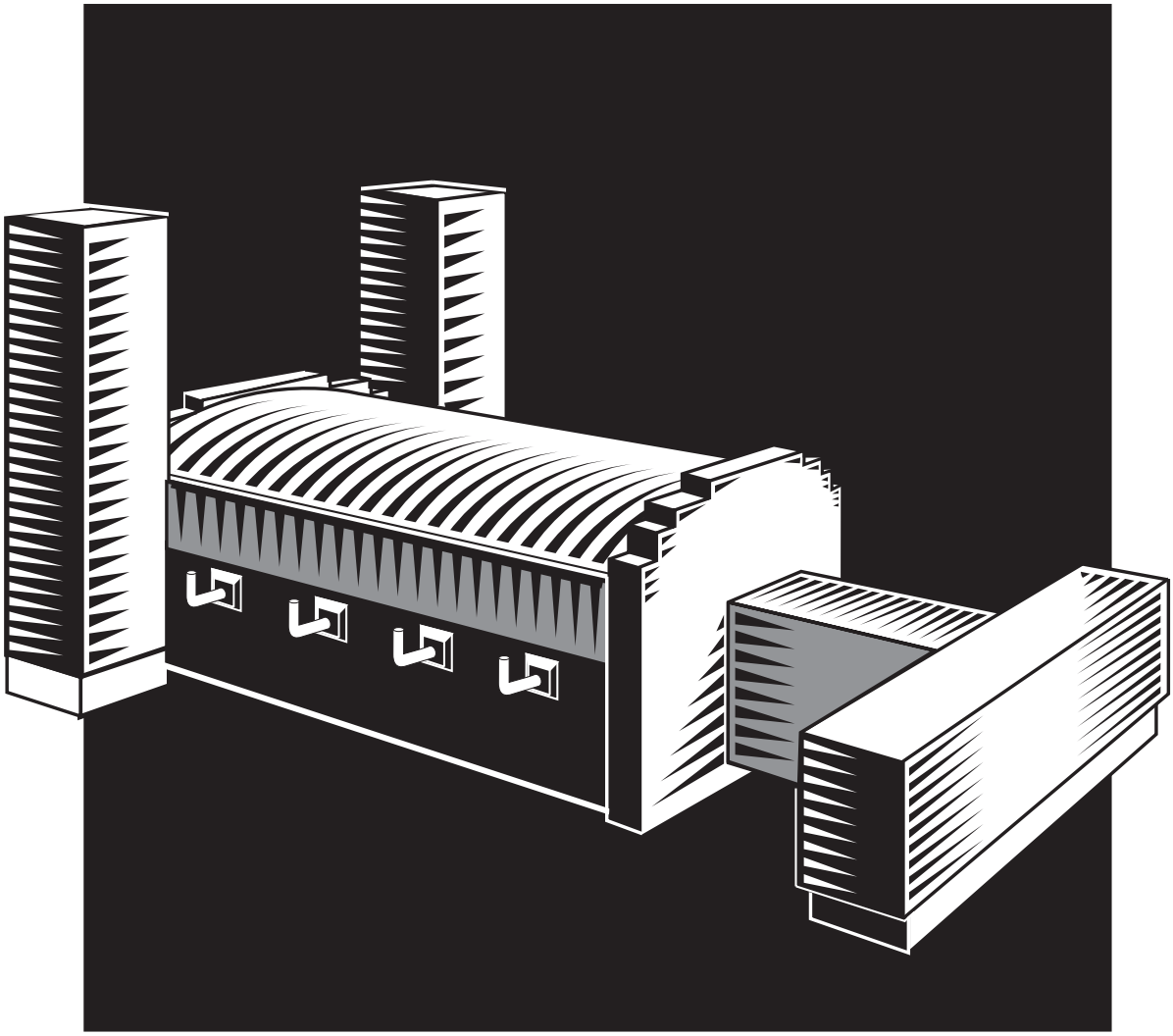
Glass Industry of the Future

Quarterly Status Reports

As of March 31, 2005



U.S. DEPARTMENT OF ENERGY

02-GA50113-03

Glass

Industry of the Future

Quarterly Status Reports

As of March 31, 2005

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Glass Projects

Development and Validation of a Coupled Combustion Space/Glass Bath Furnace Simulation 1
Petrick: Argonne National Laboratory (Techneglas)
CPS#01025

Advanced Oxy-Fuel Front-End System 2
Mighton: Owens Corning
GO13091, CPS#14233

Energy Efficient Glass Melting: The Next Generation Melter 3
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High Intensity Plasma Glass Melter 4
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Development and Validation of a Coupled Combustion Space/Glass Bath Furnace Simulation

Petrick: Argonne National Laboratory (Techneglas)

CPS#01025

QUARTERLY PROGRESS REPORT

Project Title: Glass Furnace Model (GFM) Technology Transfer Program

Covering Period: 1 June 2005 through 31 March 2004

Date of Report: 20 May 2005

Recipient: Argonne National Laboratory
9700 S. Cass Avenue
Argonne, IL 60439

Award Number: *Follow-on Program to DE-SC02-97CH10875 and DE-SC02-00CH11037*

Other Partners: Techneglas, Libbey, Inc., Osram-Sylvania, Owens Corning, Visteon

Contact(s):

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Project Team: *Elliot Levine, OIT DOE-HQ contact; Matea McCray, DOE-ID, Project Mentor*

Project Objective: The objectives of the program are to transfer the ANL-developed Glass Furnace Model (GFM) to the glass industry and to promote its widespread use by providing the requisite technical support to allow effective use of the code. Project objectives will be accomplished through the following actions. A brochure will be prepared that describes the capabilities of the code and the support that will be provided to the user. The brochure will be mailed to a broad spectrum of glass industry representatives. The GFM code will be placed in ANL's Software Shop on the internet and will be readily available for licensing on-line through the laboratory's Office of Technology Transfer. Technical support will be provided to the code users and a GFM code user group (CUG) will be established. Every licensee will automatically become a member of the CUG and will be entitled to receive technical support at no cost throughout the duration of the technology transfer program. The level of support provided is expected to allow the licensee (user) to become proficient in the use of the code. The CUG members will meet periodically to discuss their experience and the results derived from the use of the code. Further improvements in the code that evolve from the technical support activity will be incorporated into the source code. At the conclusion of this program, the CUG members will be expected to define a mechanism that they would implement for provision of any additional support they may need in the long term.

Background: A substantial effort in the previous project was expended to develop the state of the art furnace model (GFM) that can be used to predict furnace performance. This validated model has been used by the industrial participants of the project to perform extensive parametric studies on their furnaces. These studies indicated that computer modeling is a cost effective method for improving furnace performance. In an effort to improve the performance of furnaces throughout the industry, the ensuing technical transfer program has been initiated to promote the usage of the GFM in the glass industry.

Status: Program progress is presented in accordance with the work breakdown structures adopted for the program. A brief summary of progress in tasks pursued during the last reporting period follows. Those tasks in italics are not applicable to the current quarter.

Task 1: GFM brochure prepared and mailed to glass industry companies. (01/04 to 03/04) Completed.

Task 2: Licenses for GFM available on ANL's software shop website (04/04) As of 31 December 2004, nineteen licenses have been issued through ANL technical transfer. A CD with the GFM was mailed to the licensees once ANL technical transfer notified the code developers a license had been signed.

Task 3: GFM users group formed (05/04) Completed

Task 4: Technical Support Provided to GFM Users (05/04 to 11/05) During this quarter B. Golchert who had responsibility for providing technical support to the code users decided to leave the Laboratory. S. A. Lottes assumed responsibility for the GFM Technology Transfer Program from B. Golchert.

As part of this transition process an extensive review of the components of GFM was performed. These included the Graphical User Interface (GUI), the combustion space code, the melt space code, and the coupling between these components.

The review focused on identifying issues that relate to the ease of use of GFM and quality of results. The goal was to identify areas where GFM could be improved in a way that would enhance its utility and marketability.

Enhancing the Graphical User Interface was identified as an area where improvements would have the greatest impact at the least cost.

Release of GFM 2.06.00 was prepared with the following major improvements:

- The menu system was restructured to correspond much more closely to the normal work flow of preparing a case for simulation, running and monitoring the simulation, and reviewing the simulation results.
- Many user errors that previously resulted in abnormal program termination and loss of work are now prevented by various means, such as making actions inaccessible in the menu system under conditions where their initiation leads to inconsistent program states.
- User actions that are possible but may be inadvertent and result in loss or user data and work effort are trapped, and the user is warned of the possible loss of data and asked to confirm the desire to proceed before this type of action is allowed to take place.
- The user's work is now based on simulation cases, and file management of the various files needed is now done automatically by the GFM control program. This automation step is very significant because detailed knowledge of the operation of the combustion space code, the melt space code, and the information contained in the various files that they use is needed to make decisions about when to load and save files when setting up a simulation within the GUI. The user is now relieved of the burden of needing this knowledge to set up and run a simulation properly. Working with cases is very simple. The file menu allows the user to create a new case, delete a case, save a case, save a case as a new case (new case number), open an old case to continue work on it, and delete cases that are no longer needed.
- The GUI now allows the user to go back and forth between the screen with the figure (schematic) and the screen with the grid via a "view" menu. This feature provides a new capability: a series of parametric runs can now be done for grids containing user edits without the user having to reapply the grid edits for each case.
- The menu system was reorganized to bring it more in line with that of a common windows application, improving usability of the program. A number of menu items were renamed to more clearly indicate the function of the menu item.
- A brief document was written that functions as a kind of "quick start" guide to using GFM. The document summarized the steps required within the GUI to accomplishment the primary tasks of setting up, running, and reviewing the results of a simulation. The document provides enough information for a user to accomplishment many tasks with GMF without searching through the much longer and more detailed user manual.

The combustion space and melt space codes were extensively reviewed and tested. Convergence and stability of the combustion space code on several test problems was judged to be adequate for engineering computations. The complex interacting physics in these codes limits the ability of the solvers to resolve features of the flow and flow physics, such as combustion, on a single workstation within a reasonable amount of computation time. The melt code was found to have some numerical stability problems when solver iterations are carried out over a greatly extended period of time. These problems and their impact on solutions are currently being analyzed.

Finally all of the components of the GFM package were incorporated into a new modern windows installer interface. Versions of GFM 2.06.00 and beyond will be delivered with this installer. The installer includes an option to install included Visual Basic 6 runtime files for those machines that require these files to successfully run GFM. License holders will no longer need to buy and install Visual Basic in order to get GFM to run on systems that do not have the Visual Basic 6 runtime files present. The user id and password system that was required when ever GFM was run for the purpose of copy protection has been replaced by a standard serial number system where serial numbers are assigned to licensees, and the serial number is checked at the time of installation. Program and licensee information are also saved in the windows registry upon installation, and this information is checked every time the program is run. The installer automates the installation process, including building and populating the directory structure for the GFM package, creating start menu items, adding a desktop icon, and taking the user through pages with the license agreement and copyright notice. The install process is very quick and can be completed in less than two minutes.

Task 5: Periodic meetings of CUG held to discuss code usage and results (05/04 to 01/05) In view of the change in personnel and the extensive improvements being made to the GFM code, the initial meeting of the CUG (Core User Group) has been delayed. The meeting date will be set during the next quarter.

Task 6: Long-term code support mechanism established by CUG membership (02/05)

Plans for Next Quarter:

The improved GFM code will be issued to the trial license holders and technical support of the GFM will continue to be provided.

Patents:

The Glass Furnace Model software (GFM 1.0) was copyrighted (May 14, 2001).

The Glass Furnace Model software (GFM 2.0) was copyrighted (ANL-SF-01-030b) (May 17, 2002).

Milestone Status Table:

ID Number	Milestone Description	Planned Completion	Actual Completion	Comments
1	Brochure created and mailed	03/04	03/04	
2	Licensing becomes available via ANL software shop	04/04	04/04	
3	Technical support provided to code users	11/04		Ongoing

Budget Data: (as of 9/30/03): The approved spending should not change from quarter to quarter. The actual spending should reflect the money actually spent on the project in the corresponding periods.

			Approved Spending Plan ($K)			Provided to Date	Actual Spent to Date
Year/Budget Period			DOE Amount	Cost Share	Total	DOE Amount	DOE Amount
	From	To					
2004	January	March	70.0	n/a	70.0	250.0	78.2
2004	April	June	60.0	n/a	60.0		77.9
2004	July	Sept	60.0	n/a	60.0		56.0
2004	Oct	Dec	50.0	n/a	50.0	45.0	32.0
2005	January	March	10.0	n/a	10.0	110.0	8.9
2005	April	June					
		Totals	250.0		250.0	405.0	255.0

*Program started officially 01/01/04.

Advanced Oxy-Fuel Front-End System

Mighton: Owens Corning

GO13091, CPS#14233

Quarterly Progress Report

Project Title: Development/Demonstration of an Advanced Oxy-Fuel Fired Front End

Covering Period: Jan 1 – Mar 31, 2005

Date of Report: May 24, 2005

Recipient: Owens Corning
Columbus Rd., Rt. 16
Granville, Ohio 43023

Award Number: DE-FC36-03G013091

Industrial Partners: Eclipse/CombustionTec, Dan Wishnick, Kevin Cook
BOC, Neil Simpson, Greg Prusia
Osram Sylvania, Tim Jenkins

Contacts: Steve Mighton, P. Eng. (740) 321-7633

Project Team: Elliot Levine (DOE Glass Industry Liaison)
Brad Ring (DOE Project Officer)
Carrie Capps (Project Monitor)
Beth Dwyer (DOE Contract Officer)

Project Objective:
The goal of this project is to develop and demonstrate an oxy-fuel combustion system for the front end of a fiberglass melter that will reduce fuel consumption by approximately 70% creating an operating savings of approximately 40% and significantly reduce NOx and CO2 emissions.

Background:
Glass melters have successfully used oxy/fuel burners to reduce emissions and operating costs. Glass melter front ends, consisting of refractory channels that deliver glass to the forming process have traditionally used air/gas burners. Conventional front end air/gas combustion systems supply an air/gas mixture to the burner. Due to safety concerns, the mixture is not preheated as is done for air in recuperative or regenerative melter combustion systems. As a result, a significant portion of energy is required just to heat nitrogen in the air to the temperature of the combustion space. Use of oxy/fuel burners in a front end eliminates the need to heat the nitrogen and generates a hotter flame that radiates energy with a shorter wavelength resulting in improved transmissivity characteristics. These factors create a more efficient radiant heat transfer into the glass and create the potential for improved thermal homogeneity.

Background: cont'd

The resulting efficiency of a front end oxy/fuel combustion system is approximately 55% vs. only 15 to 30 % for an air gas system. In terms of gas consumption, an oxy/gas burner will use 65% to 70% less gas than an air/gas burner for the same heat input to the glass. As CO_2 emissions are directly proportional to the amount of gas combusted, the reduction in CO_2 emissions is the same (65 to 70%). If nitrogen in the combustion space can be eliminated, the potential exists for lower NOx levels as well.

The hurdle to implementation of oxy/fuel burners in a front end is two fold and relates to the fact that front ends are relatively long, narrow troughs of glass that require a large quantity of closely spaced burners (< 1' apart, both sides for an air/gas system) to distribute the energy evenly.

a) Overheating: Front end burners with outputs of 0.04 - 0.1 MM Btu/hr do not have the large flows of oxygen and gas (compared to melter oxy burners with outputs of 2-5 MM Btu/hr) for cooling of the burner. As an oxy/fuel burner has a flame temperature of ~5000 F, vs. ~3500 F for an air gas burner, overheating, soot formation and degradation of the burner or the burner block material can result.

b) Capital Cost The close spacing of side fire burners in a front end system results in a large capital cost for upgrading to oxy/fuel burners if existing burners and blocks are substituted on a one for one basis. Side fire oxy/fuel burner systems are commercially available and have been successfully supplied for trial in the past by others (Eclipse & BOC/BFH).

This project involves installation of burners in a top fire configuration, parallel to centerline of the channel, as opposed to the traditional side fire configuration in which burner alignment is perpendicular to the centerline of the channel. This allows one top fire burner, with higher flow, to replace 10 to 20 air/gas burners.

Status

The project continues at step 13 of phase 3.

Overall Project Plan

Phase 1

1.0 Develop conceptual designs of the oxy-fuel front end burner system
2.0 Perform computer modeling of the burner and block designs
3.0 Conduct single burner tests on a lab forehearth system
4.0 Develop oxy-fuel combustion systems to be integrated into front end
5.0 Perform computer modeling on combustion system integration
6.0 Conduct multi-burner tests on a lab forehearth system

Phase 2

7.0 Conduct field test of a single burner operation
8.0 Conduct field tests of multi burner operations
9.0 Conduct field evaluation of a production forehearth/channel

Phase 3

10.0 Design, engineering and system integration for field demonstration
11.0 Perform computer modeling on performance and glass quality
12.0 Prepare demonstration site for system installation
13.0 System installation and shakedown on a fiberglass melter front end.

As of Mar 31stst, the demonstration front end oxy/gas combustion system has been in operation 8 months. Evaluating emissions was the focus in this last quarter (1st Q 2005).

1st Quarter 2005 Work

Emissions Evaluation

Comprehensive analysis of front end emissions by an environmental consulting firm was organized for the first quarter based on preliminary sampling done in December with the assistance of consortium member BOC. The December samples indicated elevated levels of NOx (see Dec 04 report).

Oxy/gas burners in melters are known to reduce NOx compared to air/gas burners provided air leakage into the melter can be prevented. Based on the reduction in NOx of up to 90% that has been documented when OC composite melters have been converted to oxygen in the past, the target expectation for the front end was set at a 90% reduction.

The front end firing system was found to have an increased NOx emission. However, the overall impact of converting the melter and the front end of the melter in Jackson resulted in a net reduction in NOx emissions of 51% on a lb/hr basis. In effect, the decrease in melter emissions outweighed the increase in NOx emissions from the front end. The melter has always been the larger contributor in an air/gas process so this was not a surprise.

Taken by itself, the Jackson oxy front end had a 10 fold increase in NOx. Sampling shifted to the pilot installation in Guelph, Ontario to confirm this finding. (The pilot installation of 51 burners in Guelph was the required precursor to the scale up to the complete front end installation in Jackson.) Similar results were found.

NOx generation is a function of availability of N2 and O2 to combine in the presence of a high temperature source (flame). As an air/gas flame in a front end is relatively cold, air/ gas front ends have not been significant contributors to NOx when compared to the melter. Introducing an oxygen/gas flame to the front end provides a hotter temperature for the reaction to occur so the key to avoiding NOx generation is the elimination of the nitrogen. The nitrogen source is air if there is leakage into the combustion space so leakage must be minimized.

Leakage Detection and Sealing to Reduce NOx Generation

The leakage detection and sealing investigations were conducted in Guelph. This front end was scheduled to be shut down for a melter rebuild so the impact on production would be less than in Jackson.

While the front end combustion space is kept under a small positive pressure, air ingress / leakage may occur at seams or penetrations in the refractory if there are localized areas in the combustion space volume where the positive pressure is not present. It is also theorized that a diffusion gradient mechanism may allow for the diffusion of air into the combustion space against a minor positive pressure.

The goal was to determine the most significant air leakage sources, seal them and measure the impact on NOx generation.

Sealing efforts resulted in dropping NOx levels back to a 48% increase over the baseline levels measured at an air/gas channel as compared to the original ten fold increase, emphasizing the need to minimize air ingress.

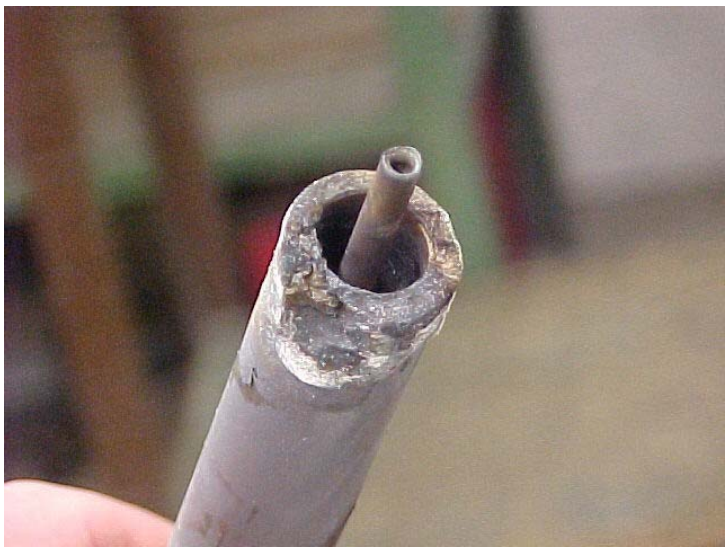
Survey of Guelph burners for gas tube oxidation

In April 05, a total of 43 of the 51 Guelph burners that had been in service prior to shutting down for rebuild were located and examined for the condition of the gas tube tip, specifically for high temperature oxidation. These burners had been in service for varying lengths of time but most had been in service for over 12 months.

Condition	Quantity
Good	28
Some scaling	13
Unusable	2

Based on these findings, and the 3 month inspection in Jackson, the current recommendation is that burners be inspected twice yearly for gas tube condition.

Fig 2 Oxidation of a gas tube and oxygen nozzle – unusable condition



Alternate burner trial

No work has been done on an alternate burner trial with consortium partner Eclipse pending written agreement that confirms intellectual property rights. Similarly, prior to any burner optimization consulting by BOC a written agreement on I/P needs to be established.

Plans for next 2 quarters

Alternate burner trial & burner optimization consulting
This work may proceed pending an I/P agreement.

Industry Workshop
Presentations will be made on the project's results at the DOE Glass Portfolio Review, Glass Problems Conference and Energy Industries – Ohio, in September and October. Details will be coordinated by the supplier consortium members Eclipse and BOC.

Patents

OXYGEN-FIRED FRONT END FOR GLASS FORMING OPERATION
US application published October 9, 2003 as 2003/0188554
PCT application published October 16, 2003 as PCT/2003/084885

LOW HEAT CAPACITY GAS OXY FIRED BURNER
US application filed June 9th 2004

Publications/Presentations

No publications or other presentations have been made this quarter.

Budget Data

Total project spending (Yr 1 + Yr2) is anticipated to be $ 1,775,606.

Project Spending and Estimate of Future Spending							
Quarter	**From**	**To**	**Estimated Federal Share of Outlays***	**Actual Federal Share of Outlays**	**Estimated Recipient Share of Outlays***	**Actual Recipient Share of Outlays**	**Cumulative**
	Start	3/31/05	Note 1	795,661	Note 1	795,661	1,591,332
2Q05	4/1/05	6/30/05	41,550		41,550		1,674,422
3Q05	7/1/05	9/30/05	50,592		50,592		1,775,606
4Q05	10/1/05	12/31/05					
1Q06	1/1/06	3/31/06					
2Q06	4/1/06	6/30/06					
3Q06	7/31/06	9/30/06					
4Q06	10/1/06	12/31/06					
Etc.							
Totals			**92,142**	**795,661**	**92,142**	**795,661**	**1,775,606**

Energy Efficient Glass Melting: The Next Generation Melter

Rue: Gas Technology Institute

GO13092, CPS#14231

QUARTERLY PROGRESS REPORT

Project Title	Energy-Efficient Glass Melting - The Next Generation Melter
Covering Period	January 1, 2005 through March 31, 2005
Date of Report	May 16, 2005
Recipient	Gas Technology Institute 1700 S. Mt. Prospect Rd. Des Plaines, IL 60018
Award Number	DE-FC36-03GO13092
Subcontractors	A.C. Leadbetter and Son, Inc. Fluent, Inc. Praxair, Inc.
Other Partners	NYSERDA – project sponsor GTI Sustaining Membership Program (SMP) – project sponsor Gas industry through FERC funding – project sponsor Corning, Incorporated Johns Manville Owens Corning PPG Industries, Inc. Schott Glass Technologies, Inc.
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Project Objective

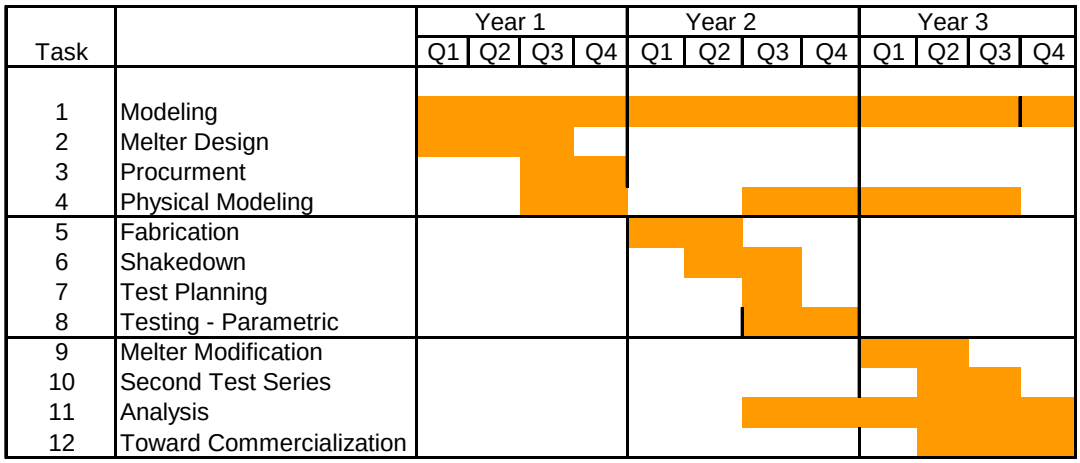
The objective of this project is to demonstrate a high intensity glass melter, based on the submerged combustion melting technology. This melter will serve as the melting and homogenization section of a segmented, lower-capital cost, energy-efficient Next Generation Glass Melting System (NGMS). After this project, the melter will be ready to move toward commercial trials for some glasses needing little refining (fiberglass, etc.). For other glasses, a second project Phase or glass industry research is anticipated to develop the fining stage of the NGMS process. Overall goals of this project are:

- Design and fabrication of a 1 ton/h pilot-scale submerged combustion glass melter,
- Extensive melting of container, fiber, flat, and specialty glass formulations,
- Detailed analysis of the product glasses,
- Preparation of a Fluent-supported CFD model of the melter to be used in parallel with further development of the NGMS technology,
- Physical modeling of the NGMS process to determine energy savings, cost savings, environmental improvements, and use of waste heat for production of needed oxygen,
- Development of a commercialization plan and timeline for further, needed components and integration of the NGMS technology.

The Work Breakdown Structure and schedule are presented below. The project team recognizes that further work will be needed after this project to bring the critically-needed NGMS into industrial use. To expedite that development, the work in this project will focus in three areas needed to demonstrate the melting and homogenization steps of the NGMS technology and to prepare for further work to commercialize NGMS. These work areas are:

- Design, fabrication, and operation of a pilot-scale melter with analysis of product glass,
- Supported CFD modeling on the melter that is available to all users,
- Physical modeling and energy balances for the full NGMS with specific planning for further steps leading to commercial implementation.

Work in each project year is divided into Tasks with milestones at the end of many of the Tasks. The integrated Task Schedule enables project team members to assign labor appropriately and to follow a critical path to reach all milestones and objectives toward the overall goal of design, modeling, demonstration, and analysis of this melting technology.



Milestones are placed at the end of many project Tasks to help sponsors and team members evaluate project technical progress on time and financial tracking. The milestones shown below will serve throughout the project as a gauge to successful completion of the work.

Year 1 Milestones	• Complete CFD model to be used by team members to design pilot scale melter • Design pilot scale melter • Procure all equipment and components for the melter in preparation for fabrication
Year 2 Milestones	• Fabricate and shake down of the pilot scale melter • Prepare test plan including compositions of glasses to be melted • Finish all pilot scale melting tests and collect samples for analysis • Complete detailed analyses of product glass properties and quality
Year 3 Milestones	• Modify melter, as needed, for second test series • Finish second test series, including at least one long term test, and all glass analysis • Finalize CFD model of the melter usable by all CFD operators • Finish physical material and energy balance model of next generation melting system (NGMS) process including utilizing waste heat for oxygen production • Complete plan for commercialization, including needed developments and stages

Go-no-go decision points are placed at the end of the first and second years of the project. At these times, the project team and sponsors have the opportunity to assess project progress and decide on continued work in the next phase (or year) of the project. The project team has every confidence that all project technical targets and milestones will be reached.

- The Year 1 go-no-go decision point criteria for continuing work will be design of the pilot scale melter and procurement of equipment and components on schedule and budget.
- The Year 2 decision point criteria for continuing work will be completion of pilot scale testing with glass formulations from all four industry segments and analyses of the product glasses.

Background

Any new melter must perform at least as well as refractory melt tanks by all technical, cost, operability, and environmental criteria while providing tangible benefits to the glass maker. A partial list of this daunting set of criteria, by category is shown below.

Criteria Category	Specific Criteria
Technical	High thermal efficiency, ability to make any glass formulation, can handle needed temperatures and oxidation conditions, meet glass quality requirements, integrates with batch handling and forming processes
Cost	Low melter cost, low maintenance cost, low energy cost, inexpensive environmental regulation compliance

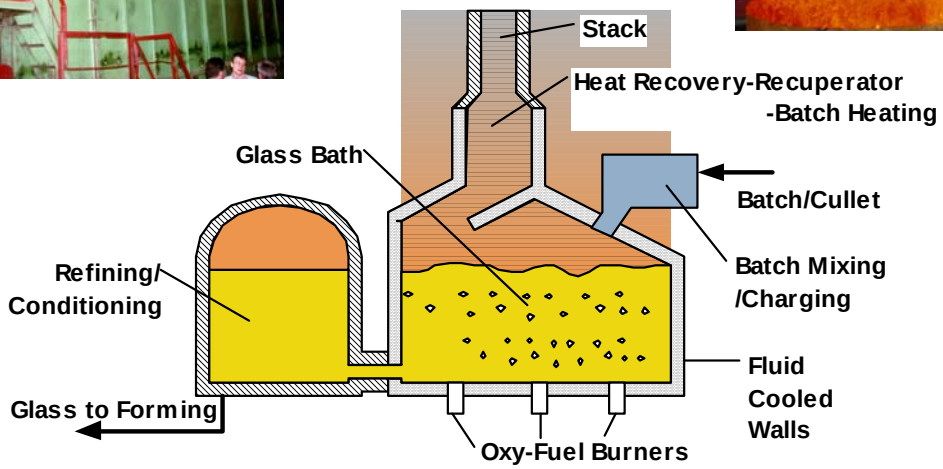
Operability	Scalable from 25 to 700 ton/day, reliable, stable operation, easy to idle, ability to start and stop, ease of access and repair, fast change with glass formulation and color, no moving parts to be abraded by the glass
Environmental	Low air, water, and solid waste, recycle-friendly

The search for a lower-cost glass melter has led technologists to suggest a segmented melting approach in which several stages are used to optimize the melting, homogenization, and refining (bubble removal) instead of the current practice of using a single, large tank melter. In this segmented approach, separately optimized stages for high-intensity melting and rapid refining are expected to reduce total residence time by 80 percent or more. This approach to melting has come to be known as the Next Generation Melting System (NGMS).

The project team has identified submerged combustion melting (SCM) as the ideal melting and homogenization stage of NGMS. This is the only melting approach that meets and exceeds all the performance characteristics of refractory tanks and also provides large capital and energy savings to the glass industry. Submerged combustion melting is a process for producing mineral melts in which fuel and oxidant are fired directly into the bath of material being melted. The combustion gases bubble through the bath, creating a high heat transfer rate to the bath material and turbulent mixing. Melted material with a uniform product composition is drained from a tap near the bottom of the bath. Batch handling systems can be simple and inexpensive because the melter is tolerant of a wide range in batch and cullet size, can accept multiple feeds, and does not require perfect feed blending.

SCM was developed by the Gas Institute (GI) of the National Academy of Sciences of Ukraine and was commercialized a decade ago for mineral wool production in Ukraine and Belarus. Five 75 ton/day melters are in operation. These commercial melters use recuperators to preheat combustion air to 575°F. All melters operate with less than 10 percent excess air and produce NO_x emissions of less than 100 vppm (at 0 percent O_2) along with very low CO emissions. A photo of a commercial SCM unit in Belarus is shown below.

In SCM (shown below), fuel and oxidant are fired directly into the molten bath from burners attached to the bottom of the melt chamber. High-temperature bubbling combustion inside the melt creates complex gas-liquid interaction and a large heat transfer surface. This significantly intensifies heat exchange between combustion products and processed material while lowering the average combustion temperature. Intense mixing increases the speed of melting, promotes reactant contact and chemical reaction rates, and improves the homogeneity of the glass melt product. The melter can handle a relatively non-homogeneous batch material. The size, physical structure, and especially homogeneity of the batch do not require strict control. Batch components can be charged premixed or separately, continuously or in portions.



A critical condition for SCM operation is stable, controlled combustion of the fuel within the melt. Simply supplying a combustible fuel-oxidant mixture into the melt at a temperature significantly exceeding the fuel's ignition temperature is insufficient to create stable combustion. Numerous experiments conducted on different submerged combustion furnaces with different melts have confirmed this. Cold channels are formed that lead to unstable combustion and excessive melt fluidization. A physical model for the ignition of a combustible mixture within a melt as well as its mathematical description show that for the majority of melt conditions that may occur in practice, the ignition of a combustible mixture injected into the melt as a stream starts at a significant distance from the injection point. This, in turn, leads to the formation of cold channels of frozen melt, and unstable combustion. To avoid this type of combustion, the system must be designed to minimize the ignition distance. This can be achieved in three ways: 1) by flame stabilization at the point of injection using special stabilizing devices, 2) by splitting the fuel-oxidant mixture into smaller jets, and/or 3) by preheating the fuel/oxidant mixture.

Several types of multiple-nozzle air-gas burners that meet these requirements have been designed and operated industrially by the GI Ukraine. The burner is attached to the bottom of the bath with the main body outside the furnace. Only the surface around the exhaust of the slotted combustion chamber is in contact with the melt. Based on the research data available on thermal and fluid dynamic stability of the combustion chamber, a model for calculating the design parameters of submerged burners has been developed. GTI has extended this work to oxy-gas burners and found them to be stable during lab-scale melting of several materials including mineral wool, sodium silicate, and cement kiln dust.

Material in the SCM melt chamber constantly moves against the walls. A typical refractory surface would rapidly be worn away by the action of the melt. To address this, the melting tank is constructed of fluid-cooled walls that are protected by a layer of frozen melt during operation. This frozen layer is constantly formed and worn away during operation. The industrial SCM units used water-cooled walls. The project team intends to use high temperature

fluids for cooling to allow useful heat to be recovered from this coolant. The heat flux through the frozen melt layer is determined by the properties of the processed material and the temperature and turbulence of the melt. It is, therefore, undesirable to superheat the melt because this increases the heat flux through the walls. Also, heat flux is lower with oxy-gas firing because melt turbulence is greatly reduced. Under normal operating conditions for silica melts, the oxy-gas heat flux is 7700 Btu/ft^2·h, equal to 2 x 10^6 Btu/h heat loss for a 75 ton/day melter. These values are relatively independent of the temperature of the coolant as any increase or decrease in the coolant temperature is accompanied by a compensating change in the thickness of the lining. Heat flux for a refractory tank is lower at 1800 Btu/ft^2·h, but with much greater surface area, the refractory tank loses more heat (2.55 x 10^6 Btu/h).

Special care must be taken to minimize fluidization of the melt which creates a large amount of droplets. These droplets, especially small ones which are formed when bubbles split, can be thrown out of the melt to a significant height. Consequently, the exhaust ducting must be protected from being covered by the frozen melt. In our design, this issue is resolved by removing combustion products through a special separation zone. In the separation zone, exhaust gas is forced to change direction and drop all liquid carryover droplets. The roof of this zone is sloped so droplets can easily be returned to the melter. This approach also reduces the necessary fluid-cooled surface area around the melting zone.

GTI holds the exclusive, world-wide license to SCM outside the former Soviet Union. Recognizing SCM's potential, GTI has operated a laboratory-scale melter with oxy-gas burners and produced several melts. Evaluation of the process has shown its potential for glass production when combined with other technologies for heat recovery, batch handling, refining, and process control. The photo above shows melt collection from GTI laboratory SCM testing.

Waste heat recovery is critical to reach high energy savings with NGMS. Adaptation of Praxair's Oxygen Transport Membrane (OTM) technology to the melter will be evaluated in this project. Praxair has been the world leader in the development of oxygen transport membrane (OTM) technology. The OTM technology is based on a class of ceramic materials that, when operated at temperatures above 500ºC, can separate oxygen from air with infinite selectivity. Because of the high temperature of operation, opportunities exist for integrating OTM oxygen production with the glass melting process to utilize waste heat. This integration is expected to result in increased energy efficiencies, reduced oxygen costs and emissions, and potential carbon dioxide sequestration.

Praxair's efforts will focus on developing and simulating OTM processes that would be ideally suited for glass melting furnaces. A multitude of process configurations will be designed. Of these processes, the top two or three configurations will be selected based on process efficiency, emission levels, simplicity, and level of integration. A preliminary economic analysis then will be performed on the selected process cycles.

The Glass Industry Technology Roadmap cites the need for a less capital intensive, lower energy cost, and cleaner way to melt glass. Incremental changes to current melting practices will not stop the loss of furnaces, jobs, and companies to the competition from alternative materials and international glass makers. The Roadmap sets high strategic goals of 20 percent cost reduction, six sigma quality, 50 percent decrease in the gap between actual and theoretical energy use, and 20 percent decrease in air emissions. At the same time, the Energy Efficiency

technical area calls for 'New Glass melting technologies'. This project addresses the following Needs expressed in the Roadmap:

- Accurate validated melter model (Energy Efficiency) – developed and supported by Fluent
- Improved thermal efficiency (Energy Efficiency) – the gap between actual and theoretical energy use is decreased by 50 percent
- Superior refractory materials (Energy Efficiency) – over 80 percent of refractory is eliminated because refractory walls are replaced with fluid-cooled walls with heat recovery
- Lower production cost (Production Efficiency) – melter cost at 55 percent lower, energy cost 23 percent lower, and glass production cost (capital, labor, and energy) 25 percent lower
- Decrease air emissions (Environmental Performance) – 20 to 25 percent decrease in air emissions from higher efficiency while NO_x is reduced over 50 percent (to under 0.35 lb/ton)

This project will demonstrate that the submerged combustion melter is ideally suited for technical and cost reasons, and better suited than any other melting approach, to be the melting and homogenization stage of an NGMS process. Also, the quality of glass produced and the flexibility of the melter to integrate with other processes will expedite development and commercial application of the full NGMS process. After this project, the melter will be ready to move to commercial trial for fiberglass and other glasses needing little or no refining. For other glasses, glass industry research or a Phase II project is expected to demonstrate rapid glass refining and to integrate the NGMS melting and refining stages.

Development of a new glass melting technology is a challenging undertaking, and no attempt to replace refractory tank melters has succeeded in the last 100 years. SCM, however, has been operated as an industrial-scale mineral wool melter for the last decade and has proved highly reliable. The industrial units are air-gas fired, but GTI has demonstrated smooth operation of oxy-glass burners on a 300 lb/h melter with several siliceous melts. This experience provides a solid basis for extending SCM to industrial-glass production.

A number of hurdles must be overcome to develop SCM into the NGMS melter and to develop the full NGMS process. The wide glass making, combustion, modeling, and engineering knowledge and experience of the project team assure the technical feasibility of this technology. No other project in recent memory has captured the commitment of such a large portion of the glass industry. This strong support makes clear that there is a great need for a revolutionary new melting technology and that these glass industry experts believe the melting technology to be demonstrated in this project is technically feasible and meets all the cost savings, energy reduction, emissions reduction, and operability needs of the glass industry.

Status – Work This Quarter

Work this quarter included 1) continued lab-scale melter testing with several glass compositions, 2) preparations for pilot melter design next quarter, 3) physical modeling of the submerged combustion melter, 4) mathematical and computer CFD modeling. All project subcontracts have now been finalized, and the glass company consortium agreement has been approved and signed by all parties including GTI, Corning Incorporated, Johns Manville, Owens Corning, PPR Industries Inc., and Schott North America..

Mathematical modeling

Mathematical modeling this quarter included continuation of CFD work by Fluent and several calculations that are summarized below.

Fluent modeling was begun with development of CFD code to describe the mixing and flow patterns in the oxy-gas fired SCM unit. Originally, work was to focus initially on the air-fired mineral wool melters, but this route was determined to not provide a reasonable baseline for future CFD modeling of the oxy-fired glass melting undertaken in this project. By the end of this quarter, CFD modeling was underway, and the following work was completed. An important note is that Fluent is focusing on improvements to the CFD code to provide a better tool for SCM modeling. The project team, including engineers at GTI, Owens Corning, and PPG, is carrying out the cases modeling SCM scenarios.

Fluent Modeling Developments

FLUENT simulation work on the Belarus mineral wool melter model described in last quarter's report was continued, using both the volume-of-fluid (VOF) and interpenetrating continua (Eulerian) approaches for the multiphase gas/liquid flow. The three challenges of the large computational mesh (driven by the 54 fully-resolved burner ports), disparate timescales leading to small simulation time-steps, and access to computer resources in Fluent India have prevented a fully satisfactory simulation of this model. However, two key conclusions emerged even from this abortive effort:

- a smaller, simpler geometry is needed for researching the many questions and details involving modeling approach;
- with reasonably complete physics, computational efficiency is a critical area to target in Fluent's Task B efforts.

On February 10, Fluent received a written problem description written by Bruno Purnode of Owens Corning for the GTI lab melter. The basic geometry of this simplified model is presented in Figure 1. The CFD Committee reviewed and refined the problem description by e-mail and telecon, agreeing that the modeling work on the Belarus mineral wool melter should be shelved in favor of this new case. To reduce the numerical challenges, the new plan envisioned a two-step, single-phase approach: first simulating the natural gas/oxygen combustion chemistry in the rectangular chamber without the glass melt, then imposing localized momentum and energy sources based on that analysis onto a second simulation of the melt without the explicit flame/combustion.

Initial attempts at the first analysis step yielded unrealistic values for both the flame temperature (5000 K) and height (nearly as long as the melt depth). Corrections for temperature-dependent specific heat capacities and radiation losses were made to reduce the peak temperature. A user-defined function (UDF) was created to impose a resistance on the combustion exhaust flow, representing the combination of viscous resistance and static head from the unmodeled melt. Ultimately, however, it was decided to merge the two steps into a single Eulerian multiphase simulation case, avoiding the use of the special UDF.

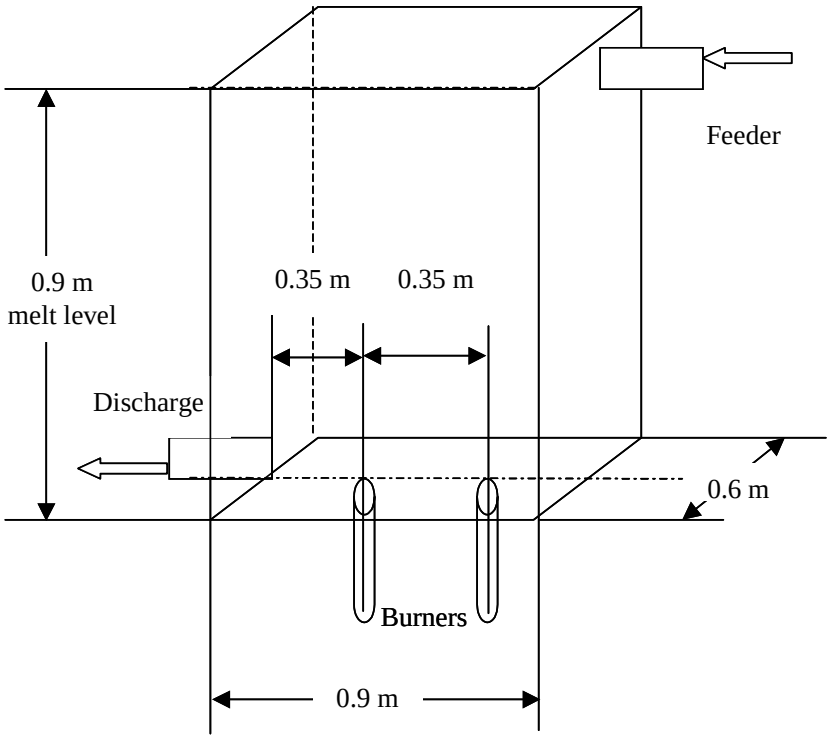


Figure 1. GTI lab melter geometry as modeled with FLUENT

After building a FLUENT mesh with about 38,000 finite volume cells, preliminary transient cases were run in this mode using Eulerian multiphase with full temperature-dependent glass transport properties, and partially premixed methane/oxygen combustion. A representative gas bubble size was scaled from actual melt test micrographs provided by GTI. For checkout purposes, the following temporary simplifications were used:

- arbitrary initial condition of a uniform glass bath at 1600 °C
- adiabatic melter walls
- uniform 4 mm bubble diameter
- charge and discharge flows neglected

The preliminary results, presented to the project team at the March 31 meeting, demonstrated clearly the basic challenge of hydrodynamic time scales on the order of one second or less, coupled with thermal (conduction) time scales of many minutes. Another notable feature was the prediction of pronounced volcano-like distortion of the melt free surface above each burner, with relatively little spreading or coalescence of the two bubble plumes during their ascent. Figure 2 presents a representative quasi-steady velocity field; it should be noted that minor fluctuations seem to persist due to large-scale eddy instability of the plumes.

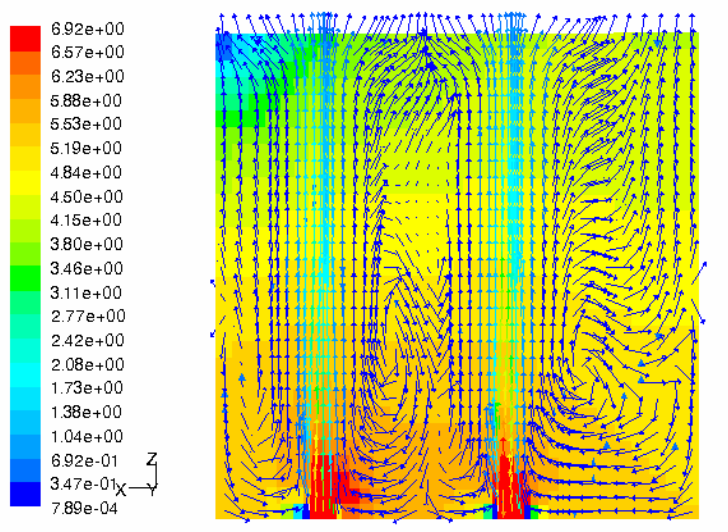


Figure 2. Results for lab melter: velocity vectors in vertical plane through center of both burners (colored by speed)

Given the imperative for faster-running simulations, several efficiency improvements to FLUENT were worked on this quarter. A three-level 2nd-order time integration scheme was implemented for the multiphase solver. Systematic unit tests were carried out for the mixture model, VOF-implicit method, heat transfer, Eulerian multiphase model, and granular flow. The implemented code was checked in for incorporation into the FLUENT 6.3 developmental (prototype) version, which will be subsequently distributed to the project team.

An innovative blended scheme (between 1st and 2nd order accurate) was constructed to avoid oscillating solutions while retaining the 2nd-order time accuracy when a large pressure gradient exists. An indicator function and its limiter were employed to compute the blending factors between the two schemes. Early tests showed good solutions with faster convergence.

Based on the need anticipated earlier to use the VOF method for the melter analysis, the efficiency of that method was improved by implementing the CICSAM discretization method. CICSAM is a high-resolution scheme specially tailored to capture a step function smoothly in multiple dimensions. This enhancement was found to improve FLUENT solver speed by 35% in highly viscous two-fluid (e.g., gas/melt) simulations. In addition, an improved wall treatment was implemented to improve accuracy of interface advection near the walls. Figure 3 shows the improved "reconstruction" of the free surface near the wall for a simple viscous channel flow. These VOF enhancements were completed and checked in to the prototype this quarter.

Figure 3. Volume fraction contours demonstrating improved VOF wall treatment (left – FLUENT 6.2; right – new prototype)

Glass melters typically involve strong wavelength-dependent thermal radiation effects with participating media, and the SCM is no exception. The optical thickness of the glass melt, αL, where α is the absorption coefficient and L is the characteristic bath dimension, may be greater than 100 in the near infra-red spectral bands but nearly zero otherwise. Radiation algorithms need to be efficient, valid for a wide range of optical thicknesses, and sufficiently accurate on the same mesh used for the flow solution.

FLUENT includes a variety of radiation models to address diverse applications. For large optical thickness, the P-1 or Rosseland models are the most appropriate. However, only the Discrete Ordinates (DO) method allows non-gray treatment of radiation. While it is valid for the entire range of optical thickness, in practice the more expensive DO model has encountered such a slowdown in convergence rate for large αL that the overall computation time has been impractical for realistic melters.

This project is leveraging the results of a recently completed collaborative project between Fluent and Schott Glass in Germany, to enhance FLUENT speed and robustness using the DO model with optically thick bands. A prototype FLUENT version has been created with a point-coupled variant of the DO model in which the discrete energy and radiative intensity equations at a given cell are solved simultaneously, assuming values at adjacent cells to be known. This procedure is then used as a relaxation sweep in a novel hybrid multigrid scheme to accelerate convergence. This quarter, single-phase testing of the prototype established that an order-of-magnitude reduction in CPU time is possible for soda-lime glass under SCM conditions.

What remains is to couple Eulerian multiphase to radiation models in general. As reported last quarter, the framework has been completed to make radiative properties available in FLUENT on a phase-by-phase basis. This quarter, coupling to each of the FLUENT radiation models was designed and planned. The P-1 and Rosseland models were selected as the most logical initial targets for implementation. Work began to apply P-1 radiation sources to each of the phases, including separate treatments at the boundaries and interior zones.

Given the possible importance of static head on bubble size in tall melters, work began on extension of the multiphase capability for a compressible secondary gas phase. Development asks included: (a) constructing a general pressure correction scheme for compressible gas as well as liquid flows; (b) pressure boundary treatment; (c) mass flow rate boundary condition for both incompressible and compressible flows; (d) compressible effects in the energy and other scalar equations. Most of these items have been implemented in the prototype version of FLUENT and are currently under debugging and unit testing.

On March 31, Brian Golchert and Lewis Collins attended the SCM project/consortium meeting at GTI in Des Plaines, IL. A presentation was made of the goals, task status, accomplishments to date, and future plans in the CFD area. An informal side meeting of the CFD Committee was convened after adjournment of the main group. From this discussion and other fruitful exchanges throughout the day, the following key points regarding the CFD activities emerged:

1. Some members felt that Fluent's emphasis to date was overly complex – need to strive for faster, simpler analysis. Basic flow/heat transfer is the highest priority and should take precedence over elaborate models of batch flotation/dissolution, combustion chemistry/emissions, etc.

2. General consensus was reached that Fluent should transition its Task A activity to a supporting role, with the other team members leading the analysis, and continue to focus primarily on the Task B enhancements. However, an initial method "template" or "first case setup" demonstration was requested.
3. Guosheng Kang of PPG recommended that the Task B activity include incorporation of the existing *ad hoc* UDF for glass batch modeling into the latest version of FLUENT in a way that is more permanent, accessible, and compatible with the other methods enhancements.
4. It would be useful to have representative glass thermophysical properties built into FLUENT, and John Brown thought that the project team should have access to the Alfred University database. Fluent will follow up with GMIC on this question.
5. With the selection of an octagonal cross-section for the pilot melter, the first key design questions that CFD can help with are: does a single central burner provide adequate stirring? If not, how close together (or close to the wall) is optimal for multiple burners?
6. To build confidence in the CFD methods, David Rue recommended that the team simulate at least one simple case from the physical model (glycerine cold flow) tests performed by James Chen.
7. For items (5) and (6) above, the *a priori* prediction of bubble diameter was identified as a likely "weak link" among the coupled phenomena. Although this input can naturally be specified based on experimental observations, a literature survey and implementation in FLUENT of a simple estimate based on burner geometry and other factors might be helpful to remove the burden from the CFD user.
8. Given the consortium feedback, the top three development items for Fluent are
   (a) steady-state solution approach, as discussed in the next section;
   (b) completion of the Eulerian multiphase/radiation coupling; and
   (c) burner bubble size prediction method, Item (7) above.

With the Fluent period of performance being shortened to 27 months by subcontracting delays, the project is now 37% complete by schedule.

In January, Abhi Dutta, the Fluent project sub-manager, announced his departure from Fluent Inc., after many years with the company, in connection with a family move. During January and February, Fluent staff worked together to determine how best to transition the project coordination responsibilities to maximize continuity and preserve momentum. After consideration of several options and consultation with the GTI Project Manager, Fluent recommended that Lewis Collins, Director of Funded Development, take over Fluent's sub-project management activities for the remainder of the project duration.

The pilot melter top-level design information was not available on the anticipated schedule in 2004. As a result, Fluent's concept simulation (Task A) work has lagged somewhat in comparison to the plan, and the CFD results have not yet significantly aided the design effort. The resolution pursued last year, modeling the Belarus mineral wool melter as a proxy, while allowing some related observations, has not been similar enough or economical enough to provide clear conclusions about either the melter design or the analysis methods. Project management solutions implemented this quarter were: (1) termination of efforts on the Belarus melter; (2) writing off some of the labor spent on the Belarus melter in order to preserve more of

the project budget; and (3) encouraging the tool development (Task B) work to proceed ahead of plan, so that relatively uniform progress can be shown overall, consistent with the budget.

Due to the complexity of the SCM flow regime, a simulation that can provide reliable, detailed predictions based on rigorous physics remains painfully expensive. This fundamental problem has historically constrained the role of CFD in melter design. Through the preliminary SCM analyses that have been accomplished to date, it has become clear that the disparity in characteristic time scales between the fluid flows and the heat transfer is an important cost driver. Based on this finding, recent discussions with experts within Fluent have focused on how to use techniques such as pseudo-time-stepping to converge much more rapidly to a quasi-steady-state result. The tentative assessment is that, for modest oxy-gas flow rates, it ought to be possible to increase the simulation time step dramatically (and correspondingly reduce CPU time) with judicious problem setup and solver controls. This solution will be pursued in the remaining period.

The previous challenge, coupled with a lack of industry experience with SCM technology, has created large and persistent uncertainties about the optimal CFD methodology for this application. As a result, the scope of the code development (Task B) items that might make a positive impact on the melter model/tool expanded beyond the bounds initially anticipated. The completed enhancements of the VOF method, initially attractive due to its existing compatibility with radiation and the notion of large gas slugs/plumes ascending through the melt, now appears to be less relevant for what is the likely final melter analysis method. Similar comments apply to Eulerian multiphase compressibility and shell conduction. The proposed solution to this problem is twofold: (1) Fluent plans to cost-share substantial amounts of the remaining development work to complete the remaining enhancements that are now (with the benefit of a refined understanding) considered key to success; and (2) GTI and Fluent have agreed in principle to shift the application case study work of Task A primarily onto the glass consortium members, to preserve more Fluent budget for Task B. A formal revision of the Fluent subcontract Statement of Work reflecting this realignment has been discussed and will be pursued in the upcoming quarter.

GTI has an important role to play in connection with this realignment. In particular, GTI analyst and CFD Committee member Grigory Aronchik has already made significant progress modeling the lab melter with FLUENT, using a creative pseudo-fluid approach to overcome some of the numerical challenges of the gas/glass density ratio. However, as the activity proceeds to the pilot melter and the FLUENT runs become more involved, Fluent recommends that Dr. Aronchik and the other CFD Committee members be given advanced FLUENT training in UDF and multiphase topics. Bruno Purnode of Owens Corning, who just attended the FLUENT/Gambit Introductory Training course at Fluent in January as a refresher, had planned to continue with that advanced training in April but had to postpone due to a conflict. The initial project plan envisioned a two-day hands-on workshop for the CFD users (see Table 1, Task A.3c) that would be delivered toward the end of the project when the final melter model was available. In view of the evolved situation and the identified challenges, Fluent recommends that this workshop be redefined as a customized advanced FLUENT training session for all of the Committee members, to be delivered as soon as possible at a mutually convenient location.

One important action Fluent has taken in response to all of the preceding challenges is to assign Andrey Troshko, Senior Consultant and Application Specialist for Multiphase Flows, to support the team's FLUENT modeling (Task A) activities during the remainder of the project.

Dr. Troshko, an expert in the application of Eulerian multiphase methods in FLUENT, will explore the steady-state approach, guide and train the FLUENT users on the team, and coordinate with the FLUENT development team on specific enhancements.

The CFD Committee has proven to be smaller and less directly involved with the FLUENT runs than had been envisioned, and yet now potentially faces an increased responsibility to ensure the success of the modeling activity. After Fluent delivered a cost-shared FLUENT license to Schott Glass specifically for the purposes of this project, it appears that no appropriate staff are available for this activity. However, there is good potential for strengthening the Committee by engaging team members Johns Manville and Corning in the CFD modeling activity. Both glass companies are long-time FLUENT clients with substantial CFD expertise. Consistent with the realignment of CFD responsibilities, Fluent recommends that GTI exert its influence as the project leader to try to direct the contributions from these two organizations more toward the simulation aspects of the project.

At the March 31 meeting, Fluent learned that Praxair has essentially withdrawn its participation in this project due to the negative assessment of the economic feasibility of the company's OTM process for the SCM application. This circumstance prevents Fluent from delivering the FLUENT license to Praxair that was promised as a cost-sharing contribution in the proposal. The proposed resolution of this minor problem is to provide an equivalent or greater amount of cost sharing in the form of Fluent labor hours for the Task B activities as discussed above.

CFD Modeling Cases

CFD modeling cases have been calculated using a round melter for simplification of the mesh. Cases have been carried out with w single burner firing in the center of the bottom. The cases calculated to date have not been optimized, but they will be optimized as work continues. Below are results of one case depicting volume fraction, temperature, and flow pattern results.

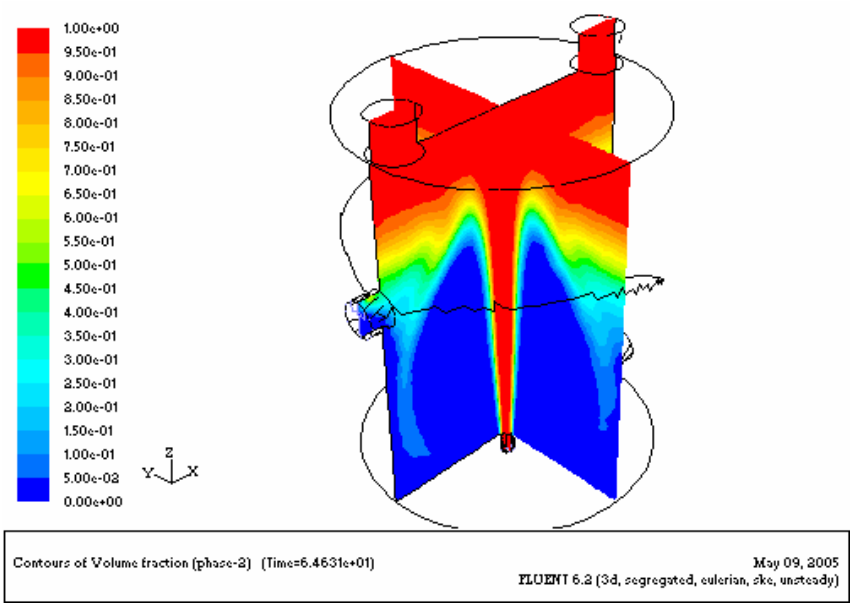


Figure 4. Volume Fractions for Single Jet Round SCM Case

Figure 4 shows that the single jet creates a channel of combustion gases that rise and heat the melt during passage upward. The melt surface is not uniform, and the CFD results show high carryover of melt into the exhaust duct. In reality, this large carryover does not occur, and this deviation is under evaluation for improving later CFD calculations.

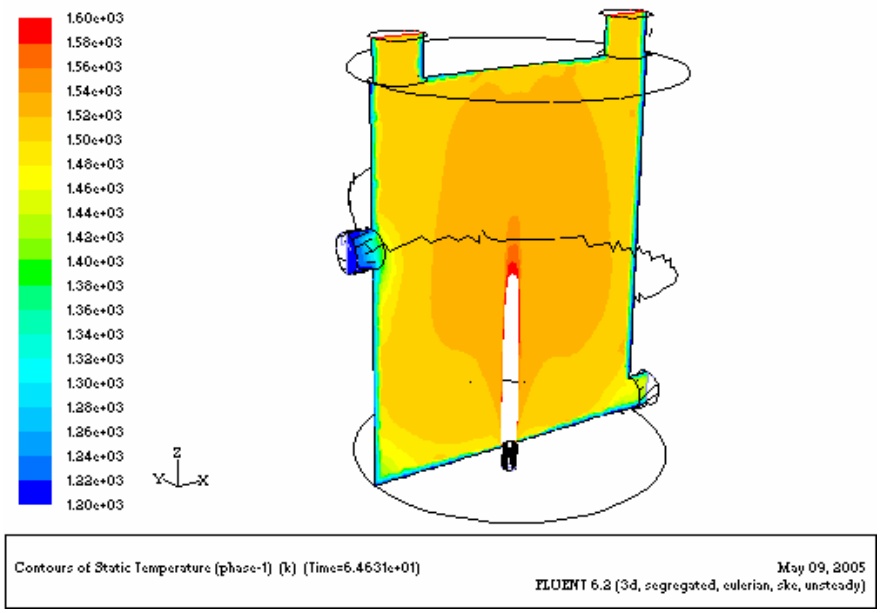


Figure 5. Glass Melt Temperature for Single Jet Round SCM Case

Figure 5 shows that with a single burner the melt bath temperature is relatively uniform with some variations around the feeder and the walls. The largest areas of non-uniform temperature are found to be in the corners at the bottom. This is a result of lower circulation of hot melt to the corners, and higher viscosity in the corners because of the water cooled walls.

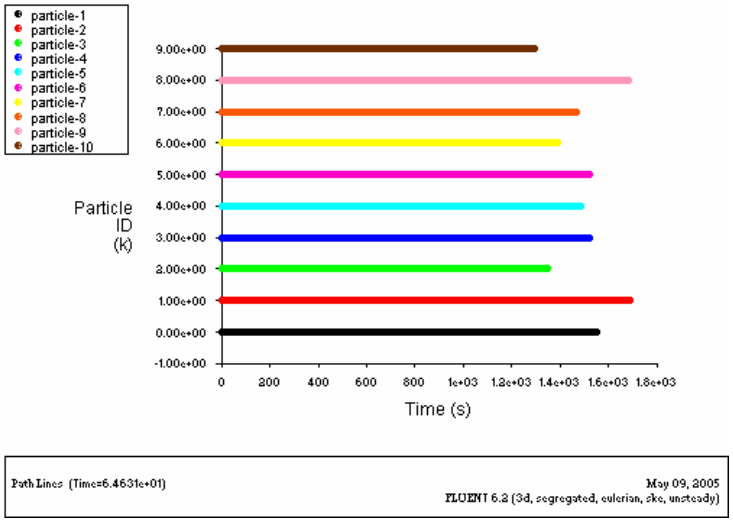


Figure 6. Residence Time for Single Jet Round SCM Case

Figure 6 compares the residence times in the melter for a series of ten batch particles. Results of this calculation show that residence times are similar. While mixing occurs and is vigorous, mixing is not random as in a fluidized bed. In a fluidized bed, some batch particles would have short residence times and others would have very long residence times.

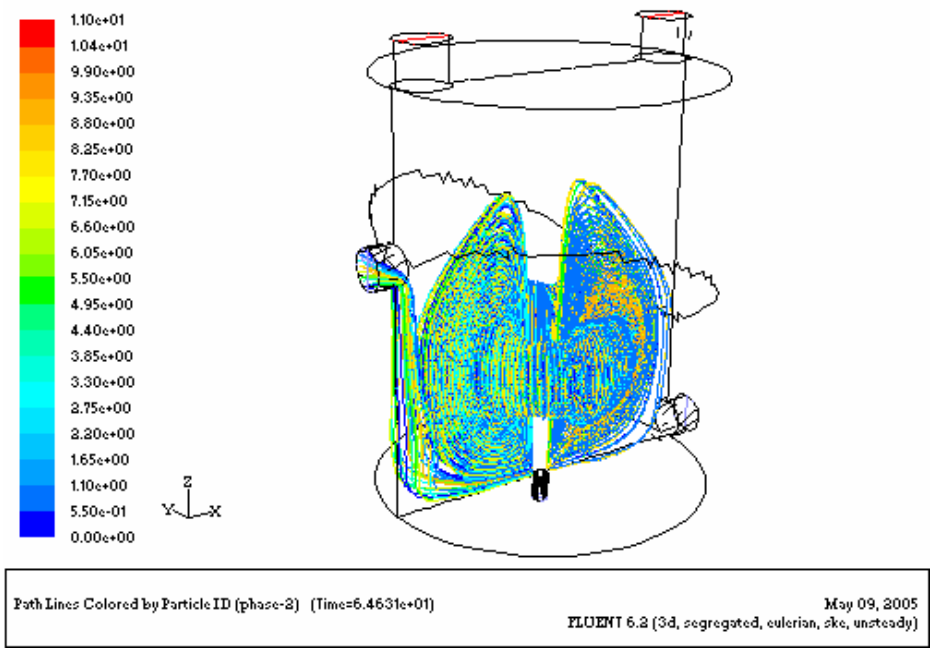


Figure 7. Batch Particle Trajectories, Front View

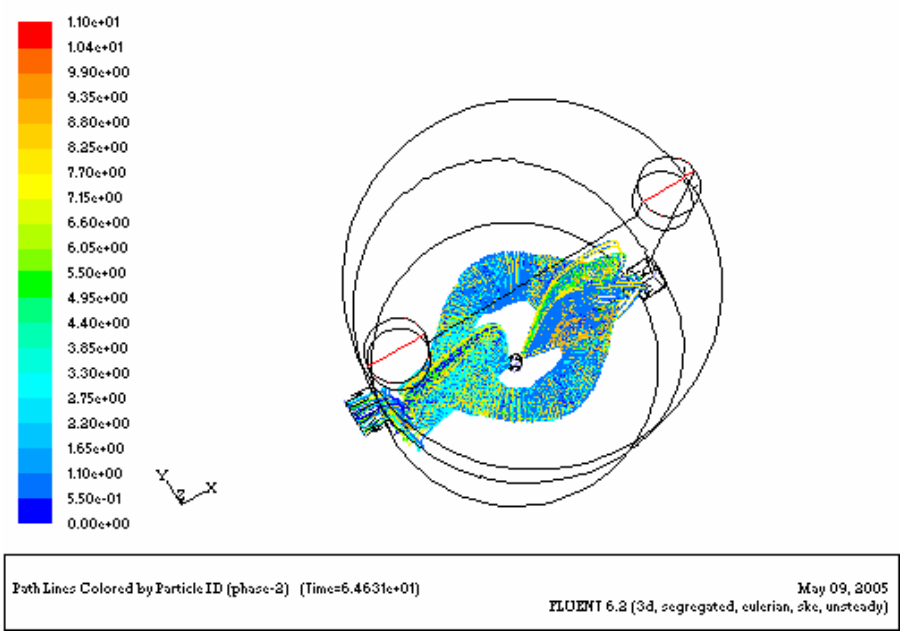


Figure 8. Batch Particle Trajectories, Top View

Figures 7 and 8 show that a burner creates a convective flow pattern in a viscous melt bath of molten glass. This creates excellent mixing and uniform temperatures while preventing batch particle bypassing to the discharge. Figure 8 shows that the convective flow patterns work around the melt chamber. A reasonable conclusion is that the optimum retention time for feed particles is reached when feed and discharge are located 180 degrees apart.

Physical Modeling

Since one of the major objectives of the physical modeling is to characterize the retention time, analytical means that quantify the retention time are needed. After several failed attempts with solid tracing particles, and UV visualization, a glycerin-dye balanced liquid was devised to with the characteristics to serve as a tracer liquid. A turbidimeter/colorimeter (Thermo Orion AQ4500) was used to quantify the color dyed sample concentration.

To understand the flow patterns that ultimately contribute to the retention characteristics, a mini-DVD was set up to document the flow patterns under all boundary conditions.

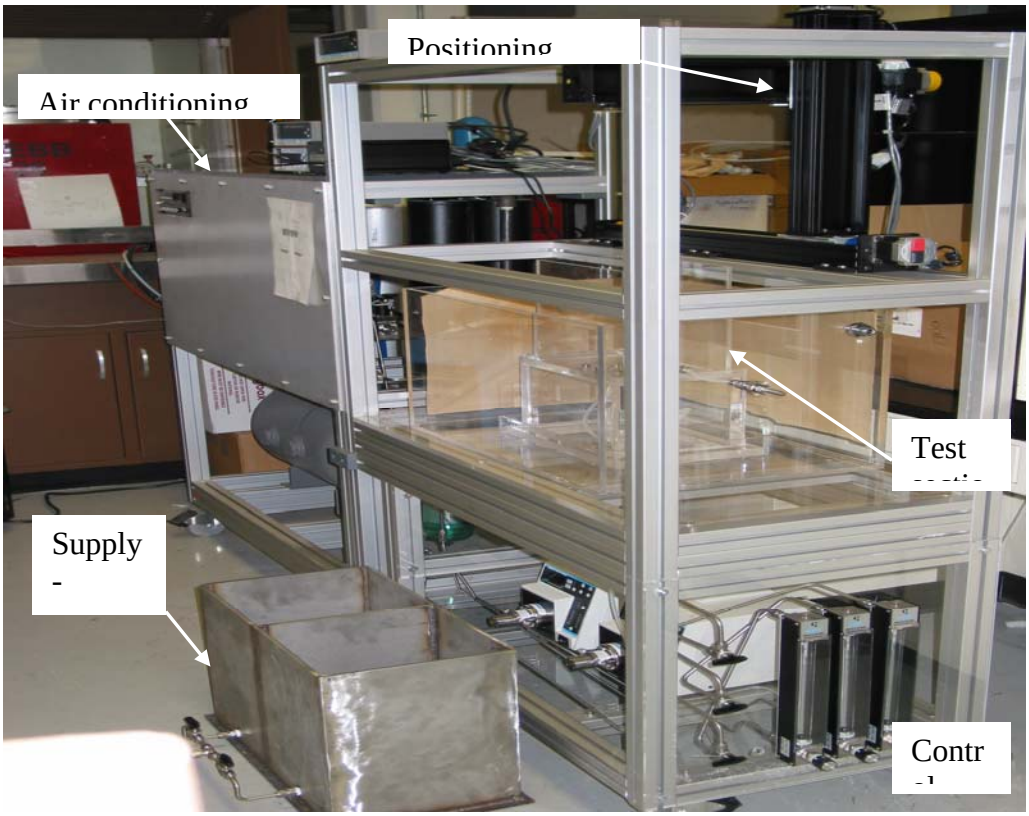


Figure 9. Experimental apparatus

Glycerin was pumped into the physical model to 4.8” in depth for a 10:1 reduced physical model. Affinity between glycerin and water is high. Continuous exposure of glycerin in ambient will result in reduction of viscosity as shown in Figure 10 (the exposure to ambient was uncontrolled and left at ambient conditions for 10 days). To avoid this problem of viscosity changes in ambient air, a fresh batch of glycerin was used for each case studied.

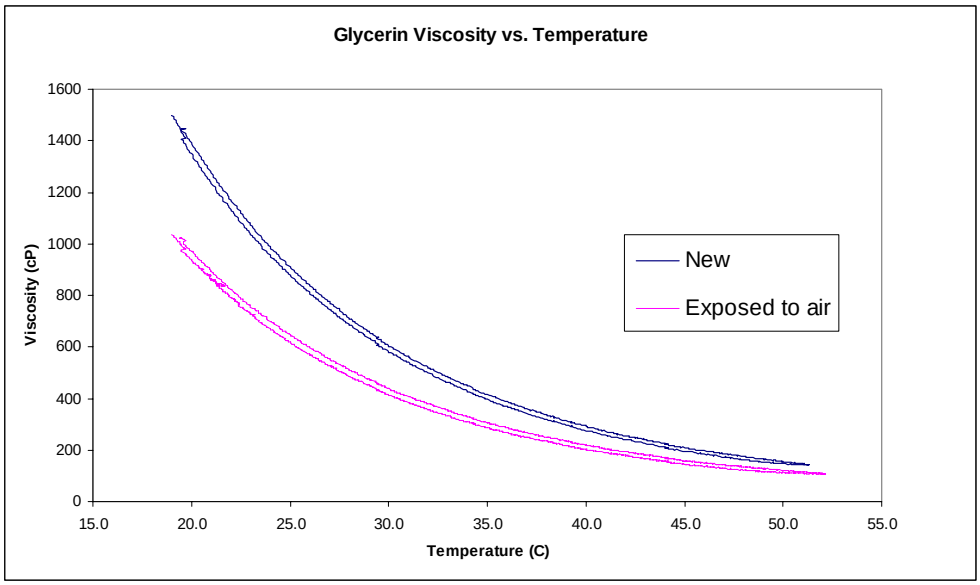


Figure 10. Viscosity change of glycerin before and after ambient exposures

Start-Up. Both charging and discharging pumps were turned on to establish the liquid loop. Under most occasions, the pump is already primed hence the priming does not need to be established to start the pumping. However, if either charging or discharging fails to pump the model liquid, the priming is established start the priming function. It is good practice to continue the liquid loop for 5 min so the dye contaminated model liquid is cleared out before the next set of tests. Facility air is then supplied to the external air supply module containing the regenerative air dryer. Since the dryer system has a damper to reduce pressure fluctuation in the regenerative cycle and needs to be pressurized to its set point, it is good practice to balance different braches of air supply into the model after the system is stabilized which usually takes about 3-5 minutes.

The physical modeling effort from this point forward was conducted under room temperature and reduced air injection. The reasons are as follows. First, to maintain the model liquid temperature at an elevated temperature range in order to simulate the submerged glass melter at a 10:1 scale requires long turn around times. This leads to drastic reductions in the number of cases/design parameters that can be studied. Second, the focus of the project team was to explore as many design parameters as possible. This means that the most important issue is the relative retention characteristics instead of the exact retention time. Third, the air injection rate was reduced so that the there is enough temporal resolution for the analytical sampling process. With these modifications in practice, one should not directly equate the retention times in physical modeling tests with SCM retention times.

The mini-DVD was connected to the computer with live video. Two and half milliliters of colored-glycerin were withdrew by pipette and injected right downstream of the charging port at the start of the test. The sampling beaker started taking samples from the discharging stream, after the discharge pump. The sample beaker was removed after accumulating 10 ml of discharged glycerin sample which usually takes about 30-40 sec. The highest temporal resolution that has been attempted in these series of tests was 1 min. Temporal resolution was usually higher at the first 10 min of the tests and subsided after the initial testing period.

Analytical Measurements and Data Reduction. Each collected sample received a time mark, was diluted with 3 times the water, and was placed in an optical sample vial designed for the turbidimeter/colorimeter (Thermo Orion AQ4500). Each sample was measured three times in a replicated order to accommodate and potential calibration constant shift in the colorimeter. All data was normalized and compared among different boundary conditions tested.

System Repeatability Test. To validate the repeatability of the analytical method and the physical model operations, a repetition of the same center firing case was conducted in the rectangular 8:5 model. Each sample set was measured with the colorimeter three times, and the results are shown in Figure 11. After a similarity study through Student's t test, it can be concluded with 95% confidence that the analytical means that we have adapted in the tests along with the physical model operation yielded statistically similar results (tests are repeatable).

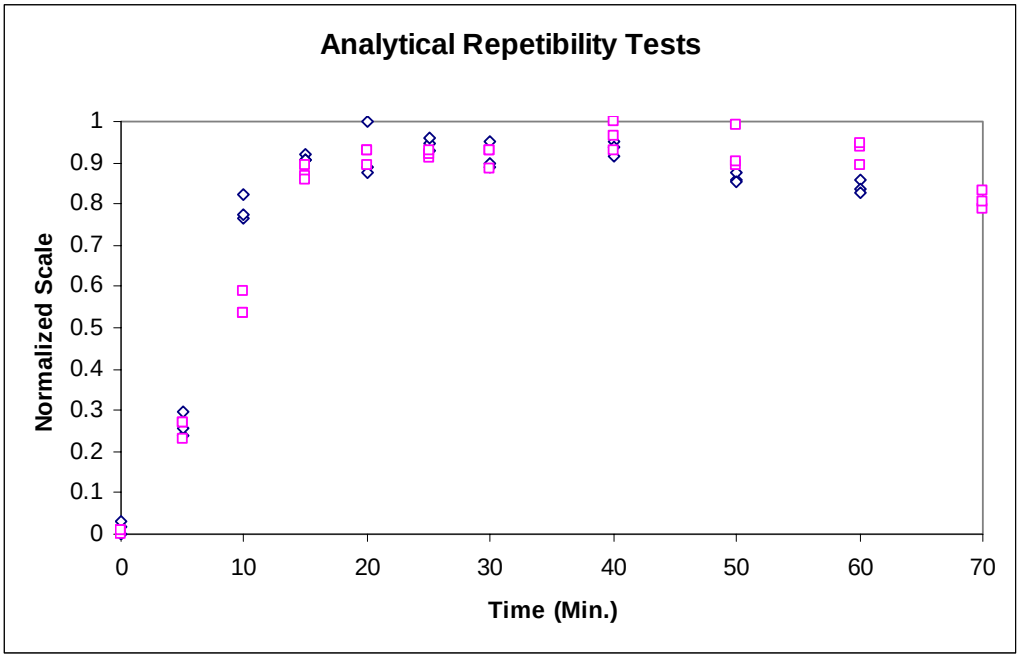


Figure 11. System Repeatability Test

Rectangular 8:5 Model Tests. Retention characteristics tests were conducted for an 8:5 rectangular physical model. The length to width ratio matches the ratio used in the commecail 3-ton/h air-fired mineral wool melters. Retention results are shown in Figure 12. Total air flow rate was kept at a constant (31 l/min) and was spread among two or three nozzles with even or uneven flow distributions. Among all the boundary conditions tested, the two jets 'firing' from left and right nozzles had the best retention characteristics.

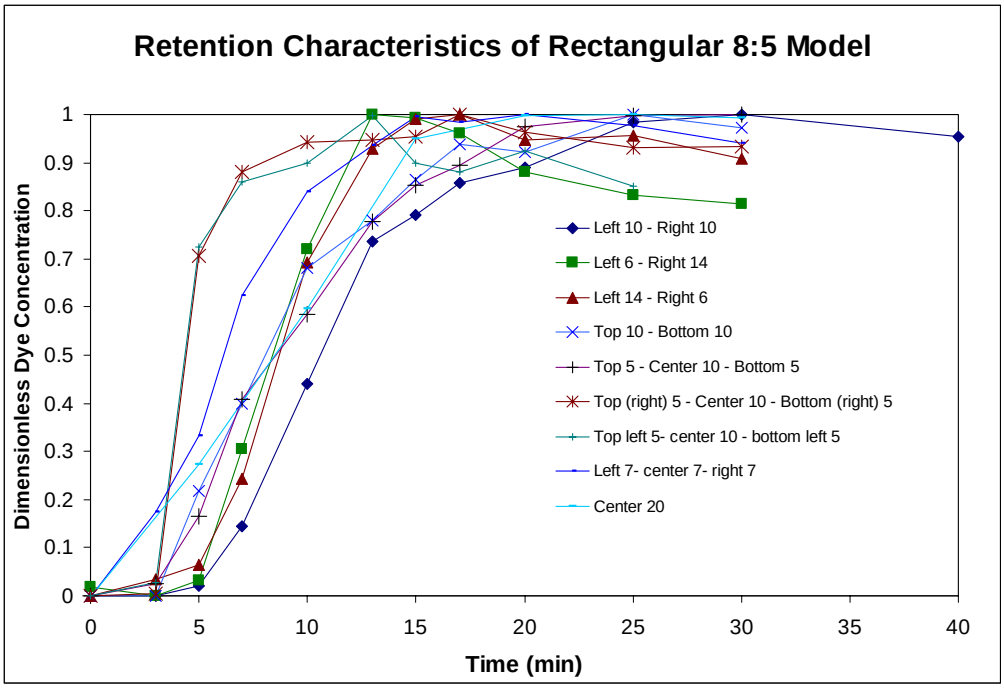


Figure 12. Retention Curves for Rectangular 8:5 Model

One important observation is the dye liquid, injected from the charging port, leaked through the planes of symmetry at the free surface of model liquid to the discharging port. This phenomenon is especially important for those conditions with nozzles close to the side walls. This observation can be explained through wave theory which states that each point at the wave front can be considered as a new point wave source. As one wave front approaches the side wall which is in a different shape to the wave front, the first point on the wave front that comes in contact with the wall will generate a new wave that contains components in the transverse direction (perpendicular to the direction of this new wave). The transverse component propels/carries the model liquid in the transverse direction and results in a leak through the planes of symmetry. On the other hand, if the wave front comes in contact with a wall that is in the same shape, as the wave that comes in contact with the wall, all transverse components would cancel each other out. Therefore, the only driving force would be molecular diffusion.

Round and Octagonal Models. The observations from the rectangular physical model and the interests among consortium members led to a round physical model design. An octagonal model, that has similar symmetry to a round model but is easier to fabricate in full scale, was also built for comparative study. Both models have multiple charging and discharging ports with 9 holes at the bottom of each model for test flexibility.

Retention characteristic tests were commenced with model liquid maintained under room temperature (same as previous tests with rectangular model). The air injection rate was kept constant at the same level as previous tests, so relative retention characteristics can be compared. The boundary condition that exhibited the best retention with the rectangular model was included with round and octagonal model results in Figure 13. As shown in the figure, retention characteristics of the round model with opposite charging/discharging and the octagonal model exhibited 250% improvement over the best case wtih the rectangular model.

The results suggest that a pilot melter with a circular or octagonal foot-print may provide maximum the retention time. Due to the similar octagonal and round chamber retention curves and the relative complexity of fabricating a round melter, the pilot melter is suggested to be in octagonal shape with center firing. While this is attractive, other factors must be considered. These factors, not accounted for in the physical model, include temperature profile, viscosity, burner kinetic energy, surface area of combustion gas heat exchange, and solid-liquid flow. CFD modeling, testing, and intuition must be used to design the pilot-scale melter.

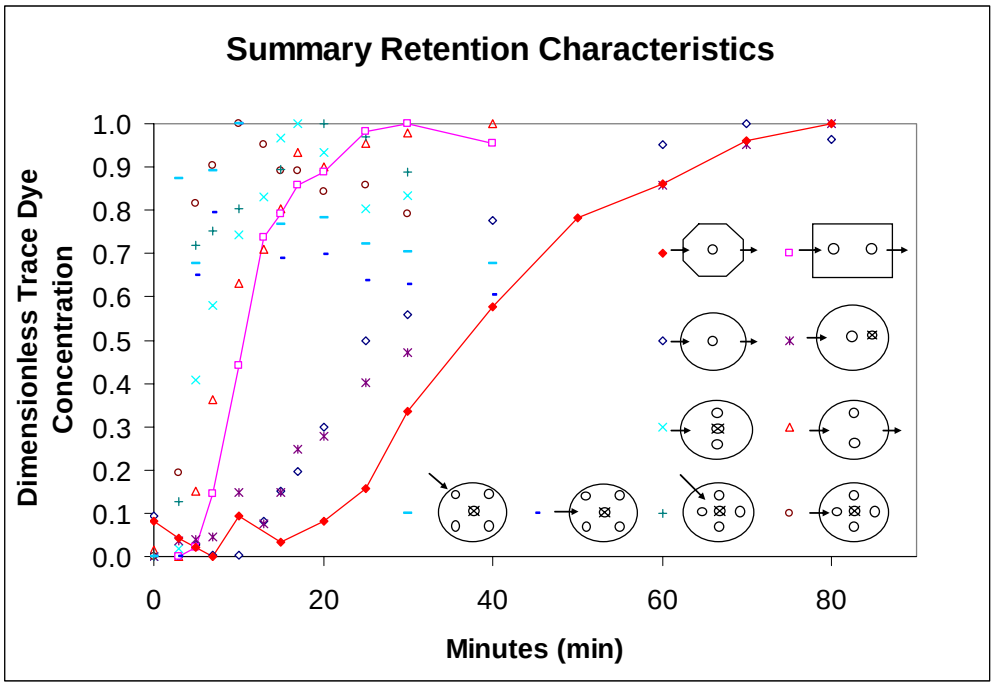


Figure 13. Retention Curves for Round and Octagonal Models
Octagonal with Two Burners.

There are concerns regarding higher shear rate and reduced heat transfer surface area with a single nozzle firing at the center of a round or octagonal melter. Therefore, tests with two 'burners' firing and their effects on the overall retention were investigated. Tests showed that, as with the rectangular model, significant changes in retention time are realized with two nozzles in different positions and with different spacing. Overall, the single center jet, with maximum symmetry, provided much better retention times than any of the two-jet cases. However, two-jet cases with the octagonal chamber provided better retention times than the best two-jet case with the 8:5 rectangular model.

Lab-Scale Melter Final Assembly and Testing

Final installation of the oxygen system was completed at the start of the quarter. After calibration and burner testing, a series of four melt tests were conducted: three tests with soda-lime glass and one test with E glass. A summary of each test is presented below.

Test sl-1. This was the first test with soda-lime glass.

Melt Date: February 4, 2005

Description:

- **<u>SODA LIME GLASS</u>**
- Initial start-up/shakedown melt
- All natural gas and oxygen flows set manually on controllers
- 877 lbs of batch to melter

Notes:

- Limited oxygen flow through burners due to internal burner blockage (fixed in later tests)
- Small feed screw became jammed due the introduction of too much raw batch fed directly from the vacuum system (fixed in later tests with feeding system adjustments)
- Large amount of raw batch remained on melter floor because heat was not uniformly distributed into the batch material in this test (improved in later tests)
- No discharge possible from side port - port blocked with batch and remedied in later tests
- Discharge from rear port

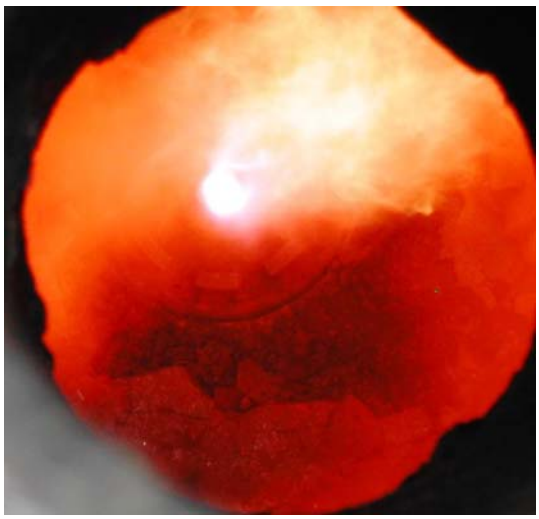


Figure 14. Test sl-1 Burner #1 Viewed from Feed Port Prior to Feeding Batch

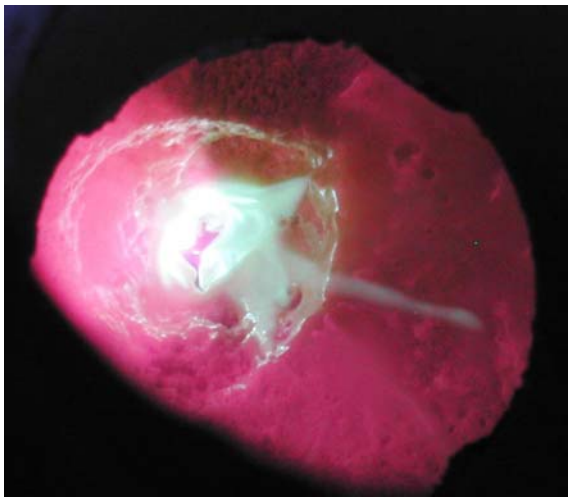


Figure 15. Test sl-1 Burner #1 Viewed from Feed Port after Feeding Batch

Figure 16. Test sl-1 Unsuccessful Attempt to Tap from Side Port

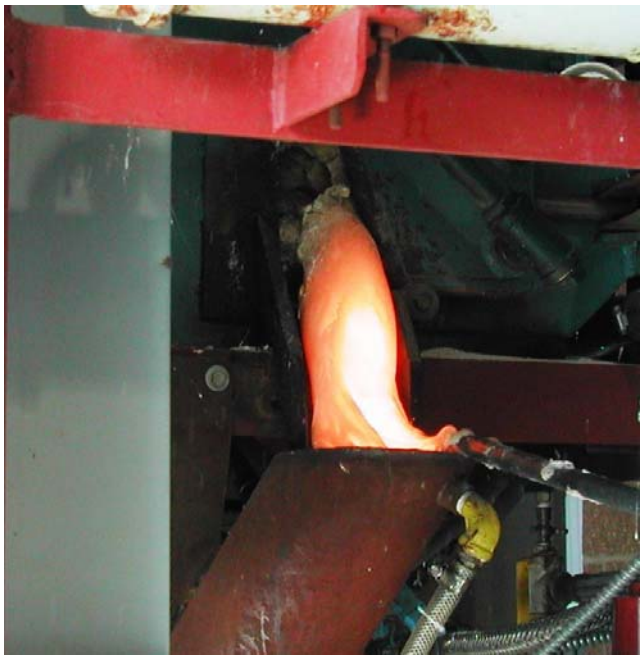


Figure 17. Test sl-1 Tapping Soda Lime Melt from Rear Port

Test sl-2. This was the second test with soda-lime glass.

Melt Date: March 3, 2005

Description:

- **<u>SODA LIME GLASS</u>**
- All natural gas and oxygen flows set manually on controllers
- 1640 lbs of batch to melter

Notes:

- Burner internals reworked to eliminate blockage
- Limited on natural gas flow due to incorrect spring in supply line regulator (fixed in later tests)
- Feed port froze over several times due to melt splashing
- Burners lost flame; possibly due to very viscous melt seeping down into burner internals.
- Discharge from rear port. Some melt was discharged from side port, but rear port was easier to use in this test. This was remedied in the next test by increasing melt temperature.

Figure 18. Test sl-2 Inside of Melter after Emergency Discharge, Picture #1

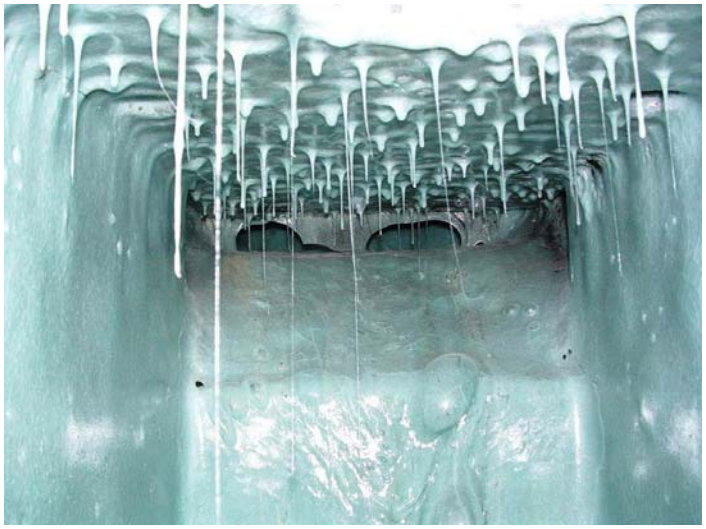


Figure 19. Test sl-2 Inside of Melter after Emergency Discharge, Picture #2

Test sl-3. This was the third test, and most successful test, with soda-lime glass.

Melt Date: March 8, 2005

Description:

- **SODA LIME GLASS**
- All natural gas and oxygen flows set manually on controllers
- 1040 lbs of batch to melter

Notes:

- Burner internals cleaned to eliminate blockage
- Kept the burner input lower than Melt#2 to prevent potential flame-outs
- Feed port froze over several times due to melt splash
- Discharge from side port with controlled starting and stopping of discharge
- Exhaust Temperature ranged from 1720ºF to 1970ºF depending on firing rate

Figure 20. Test sl-3 Discharge of Soda Lime Melt from Side Port, Picture #1

Figure 21. Test sl-3 Discharge of Soda Lime Melt from Side Port, Picture #2

Test eg-1. First melt test with E glass batch.

Melt Date: March 16, 2005

Description:

- **E-GLASS**
- Natural gas flows set manually on controllers
- Oxygen flows automatically slaved to natural gas flows via controllers
- 1520 lbs of batch to melter

Notes:

- Limited on natural gas flow due to incorrect spring in supply line regulator
- Feed port damper operational; opened only while feeding
- Vacuum system clogged while feeding raw batch
    - 720 lbs to melter prior to vacuum clog
    - Estimated 800 lbs fed manually to large screw via buckets
- Discharge not initially possible from side port (melt too viscous)
- Discharge from side port possible after burner firing rates increased to maximum
- Excessive leaks in furnace roof noticed
- Exhaust Temperature ranged from 2060ºF to 2260ºF depending on firing rate
- Bath Temperature (via optical pyrometer through feed port): 2800ºF
- Melt Temperature exiting side port (via optical pyrometer): 2650ºF
- Natural gas & oxygen pressure data (at burner) shown below

Natural Gas / Oxygen Pressure at Burners				
	Bnr #1 NG	Bnr #1 O2	Bnr #2 NG	Bnr #2 O2
NG Firing Rate	#	#	#	#
600	n/a	16.0	n/a	11.0
800	3.0	23.0	3.0	16.0
900	3.0	30.0	3.5	20.0
1000	3.5	34.0	4.5	23.0
1100	4.5	37.0	6.0	25.0
1150	4.5	36.0	6.0	25.0

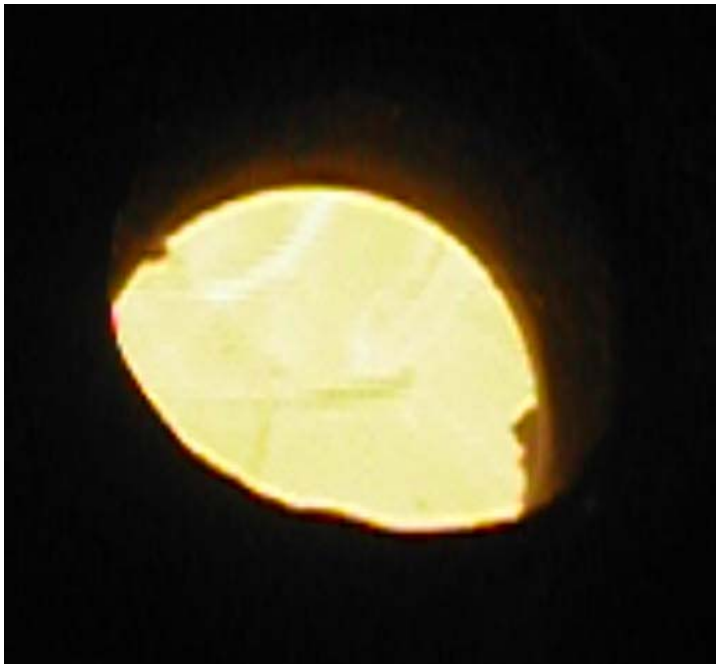


Figure 22. Test eg-1 E-Glass Bath Viewed through Feed Port

Figure 23. Test eg-1 Melter Chamber after Complete Discharge, Picture #**1**

Figure 24. Test sl-1 Melter Chamber after Complete Discharge, Picture #2

Testing Summary. Results showed that soda-lime glass can be melted and collected from the lab-scale melter in its present configuration. Results are encouraging. Glass product has been found to be homogeneous with large bubbles that will be easily refined. The batch material appears to be completed melted. Analysis shows that a layer of frozen melt forms on the externally-cooled refractory wall and that a thin layer of poor quality glass forms on top of the frozen glass layer. Based on this observation, researchers realized that discharge of high-quality product glass requires the tap piece of discharge pipe to extend a small distance into the melter to collect melt clear of the frozen glass and poorly melted glass layers.

The temperature-viscosity curve of soda-lime glass is such that discharge through the water-cooled iron plug was acceptable. E glass, however, was not easily discharged by this discharge tap. The E glass melt freezes at a higher temperature and prevents easy discharge through a cooled tap. Based on these results and operating experience with the lab-scale melter, several modifications will be made to the lab-scale melter before testing soda-lime, E glass, and LCD glass compositions again next quarter. These modifications will include the following:

- Platinum discharge pipe with controlled heating to replace water-cooled tap
- Platinum multi-point thermocouple designed to withstand thermal shock, used to monitor melt temperature
- Replacement of burners with burners made to tight tolerances and built from stainless steel.

The new burners are similar to the operating burners. The new burners will allow the project team to more carefully monitor and control the combustion process. This will provide more consistent combustion and enhanced heat transfer to the melt bath.

Subcontracts and Consortium Agreement

The subcontracts between GTI and Fluent (for CFD modeling) and with Praxair (for Oxygen Transport Membrane assessment) are in place. The final issues regarding intellectual property, ownership, and cost sharing have been resolved for the glass company consortium

agreement. The first glass company consortium members signed the agreement last quarter, and the others signed this quarter. GTI has sent contracts to the five glass company partners for their cost sharing on the project.

CertainTeed has withdrawn from the consortium because of concerns expressed by their parent company. The project team members regret the loss of CertainTeed and the loss of technical input from their representative, Terry Berg. The project team still meets all cost sharing requirements for the project award agreement.

Project work continued this quarter with A.C. Leadbetter and Son, Inc. engineers for design and fabrication of the pilot-scale melter. Leadbetter and GTI engineers are working together to complete design and fabrication of the pilot-scale melter. This teaming arrangement will be reviewed next quarter to determine if GTI will continue to retain A.C. Leadbetter or if the work can be carried out by GTI engineers alone.

Project managers put a sub-contract in place at the start of the project with Prof. Leonard Pioro, the developer of the SCM technology. In meeting with him in December 2003, engineers discussed melter operation, melter components, and melter shape. The melter can have a round cross section. This offers several potential advantages, including lower heat losses through the walls and better control of batch charging and exhaust gas removal. At this time, however, the round cross-sectioned melter is unproven. CFD modeling and physical modeling of the melter will both include rectangular and well as round cross sectioned SCM units. Dr. Pioro's work this quarter focused on burner design and evaluation of the potential for evaporative cooling to reduce water use and cut heat loss to the walls. Work has now been halted with Dr. Pioro until the pilot melter design is ready next quarter for his review and comment

A glass company consortium meeting was held on March 31, and the next meeting is scheduled for June to coincide with the next melting tests in the smaller lab-scale melter. Progress on modeling efforts will also be reviewed in preparation for design and fabrication of the pilot-scale melter. Discussions will include the topics of melt collection, obtaining a stable melt stream (the tapping approach), selecting the order of testing, and planning on support needed during testing and analysis.

Communications and education are important to the success of this project. A website (www.glassmelting.com) was established for faster communication and project-related discussions of important topics between project team members, sponsors, and interested parties. This site will be maintained by GTI with links to all member organizations. The website has a public section discussing SCM and the technology's development as well as password protected discussion sections for the project team members.

Plans for Next Quarter

Work will be carried out next quarter on a number of project activities. The primary focus will be on completing tests in the lab-scale melter, designing the pilot-scale melter, begin installations of pilot-scale melter components, and CFD modeling.

Modeling. Both physical and CFD modeling will be conducted. Physical modeling will be carried out by GTI with strong support from consultants and the glass industry partners (particularly Corning engineers). The main physical modeling work will be completed in several cases with the octagonal chamber and to then write a complete report on the physical modeling work to date.

A consultant, Dr. Grigory Aronchik, at GTI is conducting mathematical support for both physical and CFD modeling. CFD modeling will be the main focus of the modeling effort next quarter. The emphasis will switch to simplified approaches to model the small lab melter (200 lb/h) and several possible configurations of the pilot-scale melter. This modeling, along with the physical modeling, will provide important insights into selecting the configuration of the 2000 lb/h pilot-scale melter. Specific work next quarter in CFD modeling will include:

1. Numerical issues running cases using the implemented DO radiation model with the Eulerian multiphase model.

2. Numerical issues of improving turbulence dispersion of bubbles for multiphase models will be researched. The current models for turbulence dispersion may not be adequate and might need some enhancement for this application. Our plan is to conduct a literature survey on the existing models and to develop a new turbulence dispersion model to capture the effects of bubbles on turbulence more accurately.

3. The GAMBIT mesh will continue to be refined as necessary based on the CFD results of the model.

4. A new GAMBIT and FLUENT model will be evaluated and enhanced for the pilot melter being developed. Fluent will work collaboratively with GTI and other consortium members to come up with modeling requirements and the details of the simulations that will be needed. It is expected that both physical modeling and numerical modeling will guide the final design parameters for the pilot melter. The boundary conditions, material properties, and other model parameters for this FLUENT model will be developed jointly by Fluent and the consortium members.

5. The FLUENT model will be refined as the simulation progresses, and may include modifications to the following:

    - burner inlet boundary conditions for air/gas velocity, temperature, mass fractions, etc.
    - boundary conditions for heat transfer on the walls to capture the cooling effects
    - exhaust boundary conditions
    - addition of a batch inlet boundary condition
    - addition of batch melting modeling
    - glass and gas properties

The model will be modified to allow the user to change some of the boundary conditions and material properties. An attempt will be made to capture the effect of radiation using the optically thick assumption (Rosseland approximation).

The project team has chosen to cease evaluation of the Argonne Glass Furnace Model (GFM) as a comparison with the Fluent model. A copy of the GFM code was obtained by GTI, and work was conducted at GTI to determine the strengths and weaknesses of the Argonne model. Argonne staff have provided basic training and have agreed to help get the model

running. Initial feelings are that the GFM models radiation heat transfer well but may not have sufficiently robust hydrodynamic modeling to describe submerged combustion melting. The GFM has been found deficient in robustness and interfacing tools and incapable of meeting project needs. Any improvement in the GFM to produce a reliable CFD model that can be used to model SCM processes will enable to team to re-examine this modeling approach.

Pilot SCM Melter Assembly. GTI and A.C. Leadbetter have completed initial design and construction of the pilot melter system. This system currently uses the lab-scale melter along with other equipment sized fro the pilot melter. Work is underway to design the larger 1 ton/h melter. That work continued this quarter and is planned to be completed next quarter. Pilot-scale SCM construction is planned to begin by the end of next quarter This will include the melter, the burners and combustion control system, sensors and control equipment, an improved platinum discharge pipe, and a more reliable feeder system. The peripheral units (batch hopper, feeder, baghouse, melt removal, sample collection, etc.) were installed last year and are being used in tests with the smaller 200 lb/h SCM unit at GTI. All major systems, including the oxygen system are now installed and operational. After initial burner shakedown, the smaller, existing pilot melter has been used for tests this quarter and next quarter with multiple glass compositions. These small-scale test results, along with physical and CFD modeling results, will be used as input to the pilot SCM design process. The 1 ton/h melter is being designed, fabricated, and installed for much more extensive testing in 2005.

Data collection will continue. This will include collection and/or translation of relevant SCM papers and publications, further discussions with Prof. Pioro when needed (but not planned at present), and calculations and designs by Dr. Olabin of the Gas Institute of Ukraine. Dr. Olabin will continue the 1 ton/h melter design work that is already underway. Articles related to compatible rapid refining techniques will also be collected and reviewed. Calculations will be completed this quarter to assess the optimum wall design (with and without refractory) to minimize heat loss and to determine the pluses and minuses of rectangular and round melter footprints.

Peripheral questions continue to be evaluated. These include determining any potential for devitrification in the SCM unit and assessing the possibility of metal contamination of the glass by melt reaction with the melt chamber walls. Literature will be reviewed. Experts will be consulted. Lab experiments, if needed, will be set up and carried out, probably by the glass company partners. Devitrification can be minimized by decreasing 'corners' in the melter where glass in not at high temperature and is not moving. The pilot-scale melter design will minimize 'corners' by eliminating all 90 degree angles.

Testing. The lab-scale melter (200 lb/h) system with complete feed, discharge, sampling, exhaust gas cleaning, baghouse, and control will be operated next quarter. Three batch materials, a soda-lime, and E glass, and an optical glass, already provided by glass industry partners will be melted using the lab-scale melter, the new platinum discharge pipe, new burners, and new thermocouples to monitor melt temperature. Performance of the new components will be evaluated for proper inclusion in the pilot-scale melter being designed next quarter

Patents

GTI holds world-wide rights to the submerged combustion melting technology outside the former Soviet Union. GTI also holds a patent covering portions of the technology. A new

patent covering the combustion system used for oxy-gas firing was completed and submitted with the U.S. Patent Office in April, 2004.

The project team has formed a consortium to develop the NGMS technology. GTI has agreed to provide the glass company members of this consortium royalty-free rights to submerged combustion melting for glass production. In return, the glass company consortium members have agreed to support the project with cash, man-hours, testing assistance, modeling, and technical support. Other companies will be able to license the technology from the developing consortium. This arrangement is considered the most efficient means to rapidly develop, commercialize, and disseminate the NGMS and submerged combustion melting technology. The consortium agreement was finally signed this quarter. Lawyers for team members resolved final points and the agreement is signed and active. This consortium represents the first time such a large segment of the U.S. glass industry has worked together on a project, and a number of issues must be clarified to avoid legal concerns in the future.

Publications/Presentations

A number of presentations and papers have been published regarding submerged combustion melting and the NGMS technology. A presentation was made at a GMIC workshop held after the 7th International Conference on Glass Fusion in Rochester, NY held in July, 2003. A paper was presented at the second Natural Gas Technology Conference in Phoenix, AZ in February, 2004. A presentation was made at the DOE ITP project review meeting in June, 2004. An introductory presentation was also made at the DGG, Germany Glass Society, meeting in Nurenmurg, Germany in June 2004. A presentation was made last quarter at the American Ceramic Society (ACerS) Glass and Optical Materials Division (GOMD) in Port Canavreal, FL in November, 2004.

Milestone Status Table

This project is divided into twelve Tasks over a three-year period. Tasks 1 through 4 are scheduled for Year 1 (Phase I). Tasks 5 through 8 are scheduled for Year 2 (Phase II). Tasks 9 through 12 are scheduled for Year 3 (Phase III). Project work began this quarter and is completed covered within Year 1. Thirteen milestones have been defined covering the full project. Progress toward milestone completion is shown below.

Mile-stone	Milestone Description	Planned Completion	Actual Completion	Comments
1	Initial working CFD model written and tested	Sept. 2005		Continued this quarter
2	Design pilot scale melter	June 2004		Continued this quarter
3	Procure equipment for pilot scale melter	Sept. 2004		Continued this quarter
4	Fabricate pilot scale melter	March 2005		Completed last Quarter and continuing in next 2 quarters for larger pilot melter
5	Prepare test plan	March 2005		Started last Quarter
6	Complete pilot scale melting tests and collect samples	July 2005		Begun this quarter

7	Complete all sample analyses	Sept. 2005		
8	Modify melter as needed	Dec. 2005		
9	Complete second test series	June 2006		
10	Finalize CFD modeling and physical modeling	Aug. 2006		
11	Complete OTM analysis	June 2006		
12	Complete development plan	Sept. 2006		

Budget Data

The DOE contract was dated September, 2003, and work began in Oct. of 2003. The NYSERDA contract for co-funding was finalized last quarter. Gas industry co-funding through FERC funds for $700,000 are in place, and the SMP portion of gas industry co-funding will be put in place during years 2 and 3 of the project. The glass industry consortium has finalized the consortium agreement and billings will begin next quarter. GTI will enter into identical contracts with each of the six glass company partners. The overall project budget, and spending to date, is shown below. Only cash funding is shown. In-kind cost-sharing by Praxair, Fluent, and the six glass company partners is not shown.

			Approved Spending, $K			Actual Spending, $K		
Phase / Budget Period			**DOE Amount**	**Cost Share**	**Total**	**DOE Amount**	**Cost Share**	**Total**
	From	**To**						
Year 1	**10/03**	**9/04**	**1311**	**850**	**2161**	**1192**	**178**	**1370**
Year 2	**10/04**	**9/05**	**1335**	**300**	**1635**	**598**	**429**	**1027**
Year 3	**10/05**	**9/06**	**1186**	**300**	**1486**			
Total			**3833**	**1450**	**5283**	**1790**	**607**	**2397**

High Intensity Plasma Glass Melter

Gonterman: Plasmelt

GO13093, CPS#14232

QUARTERLY PROGRESS REPORT
4-28-05

Project Title: High-Intensity Plasma Glass Melter

Covering Period: 01/01/05 to 03/31/05

Date of Report: April 28, 2005

Recipient: Plasmelt Glass Technologies, LLC
2845 29th Street
Boulder, CO 80301

Award Number: DE-FC36-03GO13093

Subcontractors: James K. Hayward
N.Sight Partners, LLC
Laboratory of Glass Properties, LLC
Integrex Analytical Laboratories
Dr. Scott Parker
Robert Kirkland

Other Partners: AGY
Johns Manville

Contact(s): J. Ronald Gonterman, 270-524-5110, Ron@plasmelt.com
Michael A. Weinstein, 303-530-2727, Mike@plasmelt.com

Project Team: Elliott Levine (DOE Glass Industry Liaison)
Brad Ring (DOE Project Officer)
Carrie Capps (Project Monitor)
Beth Dwyer (DOE Contract Officer)
Matea McCrav (DOE Technical Analyst)

Project Objective: Develop an efficient 500 lb / hr transferred arc plasma melting process that can produce high quality glass suitable for processing into a commercial article.

Background: The purpose of this project is to demonstrate the energy efficiency and reduced emissions that can be obtained with a dual torch DC plasma transferred arc-melting system. Plasmelt Glass Technologies, LLC was formed to solicit and execute the project, which will utilize a full-scale test melter system. The system is similar to the one that was originally constructed by Johns Manville, but Plasmelt has added significant improvements to the torch design and melter system. The original JM design has been shown to achieve melt rates 5 to 10 times faster than conventional gas or electric melting, with improved energy efficiency and reduced emissions. This project began on 7/28/2003.

EXECUTIVE SUMMARY

Within this project, we have now been melting glass for approximately one year. This glass melting began within 9 months of the project initiation and was a great accomplishment within itself. But in addition, tremendous progress in researching the plasma-melting of glass has been demonstrated during this year. Originally, our project proposal was based upon building on the plasma technology foundation, which was accumulated in the early 90's, of our cost share partner Johns Manville. Although we have in fact made use of their technical reports, most of our work within the past year has been original Plasmelt work. After gaining access to the JM reports early in our program, it became obvious that they did not emphasize monitoring and improving glass quality, which is one of our key goals. The early JM work only briefly explored E-glass, which is one of our core glasses of interest. As a result, Plasmelt has done a great deal of original learning with our work. Furthermore, the JM achievement of high throughput, high energy efficiency, and good process stability was not exceptional. Although the JM foundation did allow us to quickly design, construct, and render operational the basic equipment to conduct plasma melting of glass, it did not provide much guidance on the process operating conditions required to successfully achieve our goals.

With the equipment and process Plasmelt has developed, we are beginning to explore other opportunities and applications of melting technology in the glass industry. Testing of 4 different glass materials have been conducted and several more are planned for May and June. Seeing is believing in the glass industry. We are demonstrating to the glass industry a completely new technology that can be used to develop innovative products and possibly lower current operating costs within the US glass industry.

As of 3/31/05, significant progress has been made in understanding the process conditions required for a stable melter setup and a stable multi-hour "hands-off" glass melting operation. Torch designs and the torch operation have significantly improved to the point where torches with greater than 20 hours of in-service life have been demonstrated. More importantly, it appears the torches with over 20 hours of service will continue operation and may reach the 100 hour goal. With this project, we have started with a new design on these torches that allow us to manufacture the torches for a small fraction of the previous work. Repairs from normal wear cost less than $5 per torch.

Work is now underway to define the startup and operational process parameters required for stable startup and operation. Upon completion, this process definition will allow trained non-technical operators to bring up the plasma melting system, perform the routine operational tasks, and shut it down safely. This process definition also serves as the foundation for an eventual automated process control scheme that will be able to operate with minimal operator intervention.

Assessments of the initial glass cullet quality have been made. Our understanding of the process factors affecting glass quality continue to progress. Contamination by molybdenum has frequently occurred during past runs, and in the worst cases, produced a totally black glass. But we now believe we

understand the root cause of this contamination and are now essentially able to produce or prevent black high-moly glass at will. Further work to produce a high quality glass is on-going. At this stage, it is still too soon to conclude that the normal background molybdenum level of plasma-melted glass is acceptable. This background level heavily depends on several factors: the specific glass composition melted, glass bath temperatures, torch amperage, melter throughput, amount of surface area of moly in the process, and the final glass product being manufactured.

Glass quality is also determined by the seed-stone-cord content of the glass. We have recently produced some of the best glass of the program as judged from our cursory examinations in our petrography laboratory in Boulder. These samples appear to be completely melted and partially refined. Under 100 X magnification, they appear to be free of any batch stones or cords and contain multiple fine seeds. At either 100X or 400X magnifications, the best glass samples have minimal molybdenum streaks in evidence. Selected glasses have been sent for chemical analyses.

Process efficiencies have not yet been given a high priority since we have not demonstrated good process stability. To be meaningful, these efficiency trials require the ability to set up the melter in a “hands-off mode” and allow it to run continuously at various glass throughputs, and to yield reproducible results day after day. Currently, we have demonstrated efficiency numbers of 0.97 kW per pound of glass during a 300 pound per hour flow rate. This equates to 6.7 MM BTU/ton of glass vs. a goal of 4.1. Our recent success with extended “hand-off” stable process runs have now enabled us to plan meaningful efficiency experiments for May-July 2005.

In order to conduct a reliable evaluation of glass quality, we plan to send AGY glass cullet for their attempts to produce glass fibers from plasma-produced glass. Our work with a JABO patty machine encountered multiple problems and has been terminated in favor of glass nuggets produced using custom made glass molds. These nuggets will be shipped to AGY in April for the fiberizing experiments.

At this time, our glass melting throughput and efficiency milestones are behind schedule. The goal of 500 #/hr at 4.1 million BTU’s with good quality glass has proven to be more difficult to achieve than we anticipated. The delay in timing has mostly been due to our lack of process stability and to black glass-molybdenum contamination issue, which has only recently been “solved”. (The fundamental moly contamination issue is not really solved, but we have demonstrated certain process configurations where the moly contamination issue is minimized and no moly streaking in the glass is evident.) We are now confident that we can plan high throughput trials on E-glass and S-glass to be able to push forward on our goal of demonstrating 500#/hr. These trials are planned for May-July, 2005.

Finally, the preliminary version of the 2-D mathematical model has been completed by the Laboratory of Glass Properties (LGP) and delivered to Plasmelt. This code was prepared by the LGP scientists and presented by Dr. Oleg Prokhorenko to us in a Plasmelt meeting with Dr. Scott Parker, our

consultant plasma physicist from the University of Colorado. Several assumptions were debated and modified, which resulted in follow-on cleanup work that is currently underway by the LGP. A final model is scheduled to be delivered in April. From this model, validation work will be conducted before the model is further used to gain insight into the process influences on flow and temperature distribution of the glass in the plasma melter. When it is finished, we are optimistic that this model will aid Plasmelt in further optimizing the design and the operational conditions to help achieve the efficiency goals for the program.

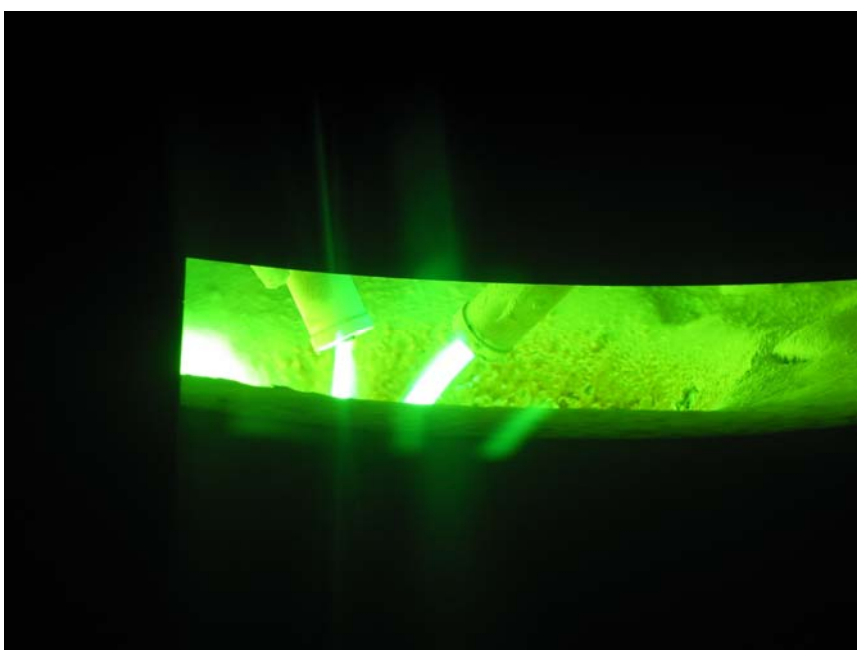
- **TECHNICAL CHALLENGES**

From the previous Johns Manville work, several critical technical obstacles were known to exist with the plasma-based glass-melting process:

I. Torch life and stability
II. Glass Quality
III. Maximum throughput of the melter system
IV. Energy efficiency

I. Torch Life and Stability

Torch lives are influenced by both design and operation. We have placed high priority on testing and conducting trials of various and sundry torch designs in order to define quickly those exhibiting the most potential. More than 50 design iterations have thus far been evaluated in the first few months of the melting work. The intensive screening process has yielded a design for a 5/8" diameter torch that shows good promise. This design has been designated the "standard 5/8 torch" and is now being used for all glass melting experiments. High potential has been shown for this design to be capable of producing 250-300 #/hr of E-glass. Based on trial results, higher glass melting throughputs up to 500 #/hr will likely require modifications to a larger diameter torch. A new design 3/4 inch torch has been initially tested. Although it shows promise in its early stage of development, there is still much work to be done to fine tune this design. The current melting operation using the baseline torch designs is shown below:



Plasma Torches in E-Glass Melting Operation

Initially, a goal of 100 hours of torch life was established for the project. Thus far, incremental improvements to design and major improvements to the operation

have currently evolved to a torch with a demonstrated life of more than 20 hours. Several of these torches were still in good operating condition when they were removed from service. Many of the life improvements made thus far relate to the operation of the torches. Several process configurations have been identified that can significantly shorten the torch life and cause premature failures. We continue to improve our understanding of the relationship between this torch operation and energy efficiency, heat transfer, batch bowl configuration, proximity of the torch tips to the batch pile, separation of the torches from each other, and the power settings. Even with our improved understanding, there remains a significant technical challenge to reach the 100-hour goal.

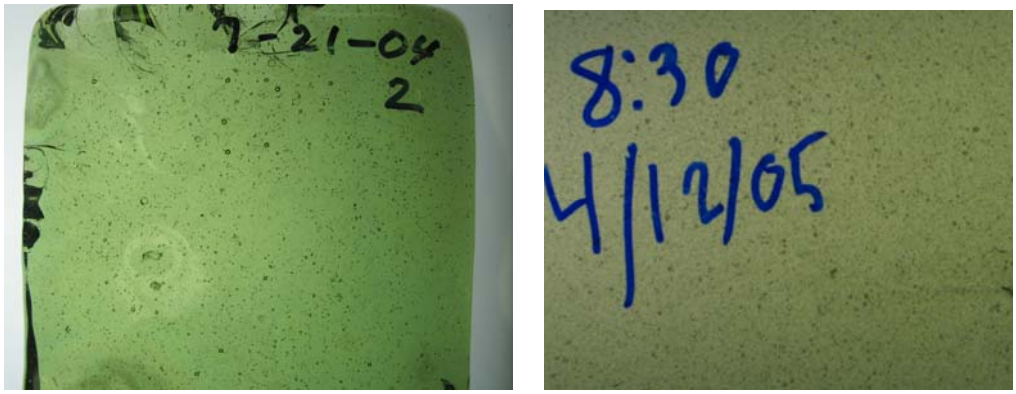
II. Glass Quality

Certainly, one of the most important technical challenges of this program is to demonstrate the potential for producing the best quality glass from the plasma melting process without the need for downstream refining and processing. The development of further refining processes is beyond the scope of this project. Although there is a finite probability that a separate refining process step will be required for plasma-melted glass to achieve the highest quality of glass, the goal of this program is to make this determination based on glass quality data and to quantify how much refining is actually accomplished within the plasma melter itself.

Glass quality is the challenge that most glass scientists/technologists deem to be the most significant fundamental barrier of this project. The amazingly short dwell times of the plasma melter, which range from 5 seconds to 15 minutes, play a direct role on the quality and consistency of the glass that is produced. Although we certainly agree that this short dwell time is a major barrier by traditional standards, our initial optimism still remains. Other than the Manville work and some early work by British Glass in the mid-1990's, there are no documented processes (of which we are aware) that have investigated the glass batch reactions and glass homogeneity at the elevated temperatures involved in plasma melting aimed at high quality glassmaking. And, we know of no commercial plasma-based high quality glassmaking operations in existence globally.

The temperatures involved in plasma melting are too high to effectively measure and we are left to postulate the thermal history of the glass itself. Attempts to measure the actual temperatures continue to be a high priority task in the project. Dr. Scott Parker is working with us as a consultant to attempt to characterize spectrally the temperature distribution and the 3-D volume occupied by the plasmas. The approach being used is plasma spectroscopy in the range of 300-900nm. Ratios of intensities of the argon species are used to determine the temperature of the plasma. Abel inversion can be used to obtain the approximate temperature profiles.

To achieve the highest quality possible, the glass dwell time is being maximized through operational controls such as a glass flow control on the bottom orifice, which will be used to meter the glass throughput. We believe this to be a key factor in achieving the highest potential for glass quality. Our optimism is, in part, based on a 21 July, 2004 experiment in which the glass was melted in the plasma melter for 20 minutes without glass flow from the exit. A photograph of this 7-21-04 glass is shown below (the small dark circles represent seeds (small bubbles). No batch stones or cord are present in either of these:



PLASMA MELTED E-GLASS SAMPLES
(Note: Apparent color differences are only due to lighting of the samples.)

Until recently, the 7-21-04 glass was considered to be the highest quality of any plasma-glass melted thus far. This "20-minute-glass" sample had previously been our glass quality baseline. Recently, we have achieved a similar or better sample glass quality as shown above in the sample marked 8:30. This latter 8:30 sample was produced as part of a normal 6 hour run and is considered to be representative of the best glass that the plasma-melting operation is able to routinely produce.

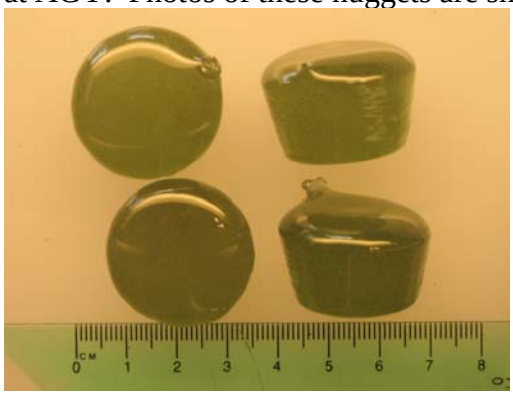
A thorough assessment of the plasma-melted glass quality is now continuing. The initial chemical analyses of the glass showed that the plasma-melted glass is essentially on-composition for E-glass with all major oxides, except boron, being within their normal range as compared to glass melted in conventional production glass melting furnaces. The boron loss was slightly higher than traditional melters.

AGY Fiberizing Experiments

There are numerous lab techniques and numerous approaches to defining and characterizing glass quality. However, in our experience, one of the more stringent, practical, and relevant tests is to fiberize glasses in small diameter multi-hole bushings as are commonly used in the production of continuous filament commercial fiberglass. The stresses encountered during attenuation are sufficiently large that any discrete micro-defects from seeds, stones, or cords will cause the strength level of the fibers to be exceeded and the filaments to suffer breakages and interruptions to the process. In short, this fiberizing process is an excellent metric of glass quality.

Since the two cost share partners for the High Intensity Plasma Glass Melter are both fiberglass companies, we initially have elected to use this method of characterizing the quality of the glass. One of the cost share partners, AGY, has agreed to conduct these trials in their commercial facility. Their commercial fiberizing process currently uses E-glass marbles, which are re-melted in single-position melters / bushings. Since this commercial process is currently set up to automatically process bulk containers of marbles, any glass cullet that is supplied by Plasmelt must be adaptable to this marble process. The original Plasmelt proposal included the task of outfitting the Boulder Lab with a marble-making commercial process. But, after reviewing the detailed costs and complexities of setting up the Plasmelt Boulder Lab to operate this marble process, we elected to substitute a patty-making process in order to realize significant time, cost, and project simplification benefits.

During the past quarter, we have taken delivery of a patty-making machine that was leased from the JABO marble company in West Virginia. The machine has been installed in the Boulder Lab along with a glass delivery refractory channel that conveyed glass from the melter to the patty machine. During January—March, several attempts were made to produce good quality patties from plasma-melted glass. Our numerous attempts did produce several hundred pounds of patties, but these were judged to be too low in quality to be considered good candidates for fiberizing trials. Several problems were experienced with this "very-used" patty machine including contamination by metals, grease, grime. Other problems of concern were the refractory particles from the glass delivery channel, and possible devitrification. All of these real or potential problems forced us to abandon this JABO machine approach in favor of a much simpler and more efficient method. This favored method is the production of hand-made nuggets from customized steel molds to produce slightly conical nuggets that are approximately 1.5 cm tall X 2 cm in diameter. These nuggets should work well for the fiberizing trials at AGY. Photos of these nuggets are shown below:



Nuggets produced from plasma-melted E-glass

III. Maximum Throughput of the Melter

All of the initial melting trials have been conducted in the 100-300 #/hr range. The method used for establishing throughput is by hand collecting patties, annealing, then weighing. These patties are collected for known times in the 15 second to 60 second range. Pull control is generally established by the diameter of the opening of the fixed

orifice, by the viscosity curve of the glass, and by the glass temperatures. Since most runs have been made with E-glass with a fixed batch chemistry, the only indirect control on glass flow rate through the orifice is by controlling temperature of the glass near the orifice.

Early trials have established the ability of the process to deliver exit glass with temperatures as high as ~3200°F. These conditions are achieved by some combination of power level through the torches, torch proximity to the batch / glass, and the torch-to-torch spacing. Batch feed-rate also has some influence, albeit a secondary one within the throughput range that is being used in this process thus far.

At this time, a "hands-off" process has been demonstrated in excess of 6 hours on several occasions. These longer trials had glass throughputs nominally in the range 50-250 #/hr. Numerous short runs have also been successfully completed. Automatic data logging equipment is being used routinely to log all process conditions during glass melting trials. Temperature monitoring is provided with a Mikron I.R. detector. This sensor is entrained on mirrors that reflect the glass stream at the bottom of the moly orifice support cylinder. Although we know from experience this temperature may be as much as 200 degrees lower than the glass collected in the ladle, it is still a valuable signal that is used to monitor the process.

We have demonstrated that throughput control can be achieved by moving the torch positions from a central position, i.e. the anode centered over the orifice, to "off-center" positions. Quite dramatic reductions in temperature of the moly orifice and therefore glass throughput have been achieved by changing these positions. However, this temperature reduction has a serious downside of reducing the temperatures within the glass pool, increasing dramatically the seed/batch stone content of the glass, and makes it even more difficult than normal to achieve a good quality glass. Recent innovations in the operating positions of the electrodes have resulted in markedly improved seed levels and essentially zero batch stones and cords. These innovations are being aggressively pursued as a means of significantly heating up the glass while avoiding the boundary conditions that are imposed by the service temperature of the moly orifice. These higher temperature operating conditions ultimately improve the seed, stone, and cord levels, which are all key components to producing a glass quality that glass companies will find of interest.

IV. Energy Efficiency

The stated goal of the program is to achieve a melt rate of 4.1 MBTU/hr melting efficiency. That number was selected as a stretch goal over the previously demonstrated work completed at Manville.

Based on this previous work, it is known that the increased power efficiencies will be achieved at higher throughputs. The increased efficiencies at the higher throughputs are primarily due to the ohmic heat transfer mechanism that is realized by the amperage and

torch position. It is only possible to operate in these positions at the higher feed rates. Further testing in April-July will validate this statement.

The highest throughput run was to date was ~300 pounds per hour. This yielded the highest efficiency. The average operational conditions at this level were:

- 415 Volts
- 712 Amps
- 295 kW

To calculate the energy used per pound of glass:

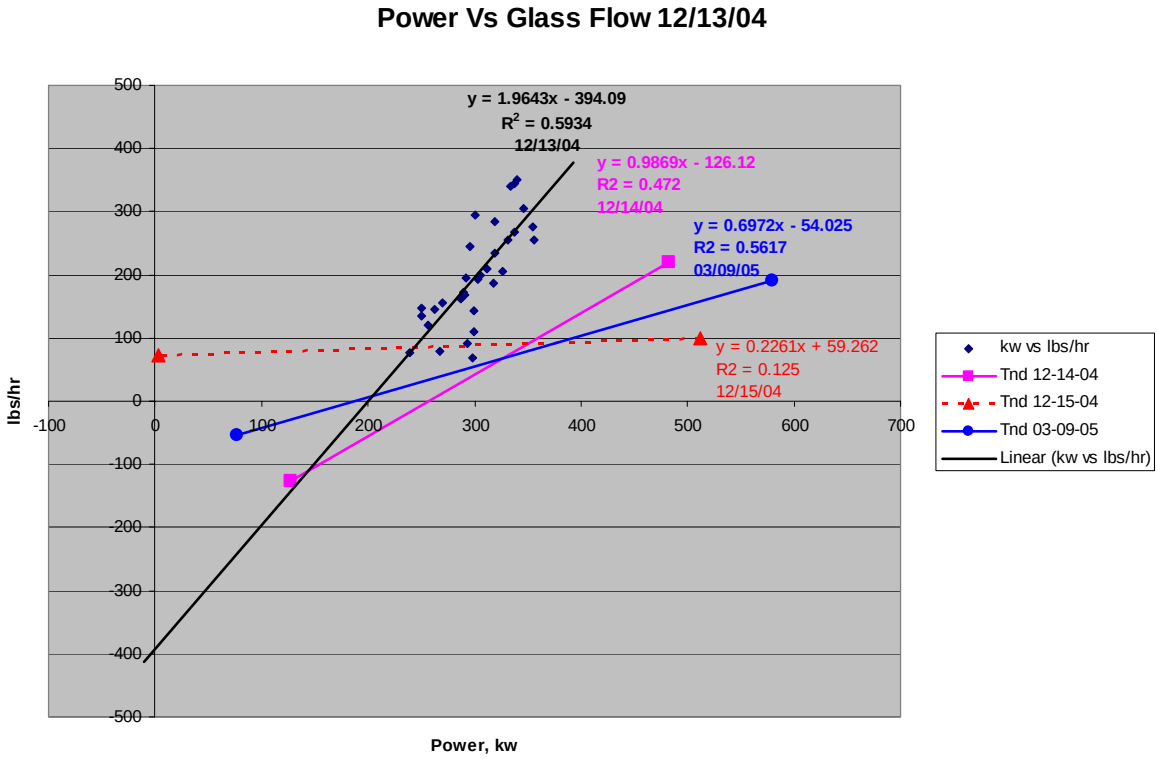
$$Power = Volts \times Amps = 415v \times 712a = 295kW$$

$$kW / Pound\ of\ Glass = \frac{295kW}{300lbs/hr} = .98\frac{kW}{lbs/hr}$$

$$1kW = 3412.4BTU/hr$$

$$0.98\frac{kW}{lbs/hr} * 3412.1\frac{btu}{hr} = 3343.9\frac{btu}{lbs} \Rightarrow 6.69MBTU/ton$$

The graphic below reflects the process throughput and energy efficiency relationship that we have deduced thus far (for E-glass only):



Major conclusions from these E-glass data are:

1. The best fit line for the 12-13-04 data shows an energy usage of approximately 1.16 kwh per pound of glass (300 # divided by ~ 350 kwh).
2. The best actual data points show ~350 #/hr @ ~340 kwh or ~ 0.97 kwh/pound of glass.
3. There is wide scatter in the data as shown by the R^2 value of 0.59.
4. Trend lines are somewhat different for different dates. These differences are normal and result from the process setup (torch positions, power, feed position, etc.) are all very influential on the slope of the curve.
5. Since these data were collected on a plasma melting process that has not yet been optimized, we fully anticipate that optimization will yield even better efficiencies at the higher throughputs that are planned for May-July trials.

ACCOMPLISHMENTS

Without elaboration, below is a list of program accomplishments to date.

1. All lab infrastructure has been installed including the glass melter, batch feed system, exhaust gas system, plasma torch system, all electrical power and control systems, cullet handling, and process monitoring.

2. More than 50 torch designs have been evaluated. A standard 5/8 torch has been designed that is in routine use and allows the process to run continuously in a stable hands-off mode for > 4 hours.
3. A process has been demonstrated that is capable of continuously melting glass in the 200 to 250 pounds per hour for several hours.
4. The standard 5/8 inch torch has been used to briefly operate the process at pull rates of ~ 350 #/hr.
5. Brief runs have been conducted in excess of 500 pounds per hour, but these were not stable and in-control operations. We have concluded from these experiments that a larger torch is required and work has been initiated on a 3/4 inch torch.
6. Preliminary chemical analyses of glass, which was collected on 6-16-04, show that overall, the analyzed glass samples were essentially on-composition, with somewhat higher losses of boron and fluorine.
7. Several preliminary assessments have been made of several E-Glass patties produced during trials. These generally show a very high seed count, some cord, and occasional un-melted batch stones.
8. The best glass quality was demonstrated on a glass sample that was melted for 20 minutes with no flow from the exit orifice. These samples have been selected as our baseline glass quality against which all future improvements will be judged.
9. Several glass trials have produced glasses with nearly the same quality as the baseline glass, but invariably, they have also included minor moly streaking.
10. Contamination from moly has been a serious problem until recently. We have now successfully defined the process boundary limits to circumvent the production of black/streaked glass. This accomplishment has been a major step forward.
11. Torch lives have improved dramatically from a few minutes on the initial designs to several hours on the current standard 5/8 torch. The torch with the longest service life thus far is >20 hours.
12. Energy consumption has on average been about 6.7 MM BTU/ton. This efficiency is much worse than the target 4.1 MM BTU/TON of glass, but is primarily related to our low throughputs thus far in the program.
13. The environmental impact of the process has not yet been assessed. However, using commercial E-glass batch ingredients, the dustiness of the initial system is known to be high. Significant work is planned for later in the project to focus on quantifying and reducing the particulate emissions as necessary.
14. A market study has been completed. Candidate early adopters have been identified. Discussions are on-going with these companies.
15. Melting trials have shown that the system is capable of melting 200 #/hr of S-2 Glass.
16. We have developed a preliminary understanding of the process settings and how these may relate to the ability to maintain a stable melting operation.

17. The design, construction, and operation have been completed for a refractory glass delivery channel that will transport the glass from the melter exit orifice to the processing area.
18. A patty-making machine has been installed and rendered operational in the Boulder Lab. Although further work is still required to improve consistency, we now have now essentially demonstrated the capability to make glass patties.
19. Several preliminary methods for glass flow control have been identified.
20. One exploratory glass melting trial has been completed on a frit composition that is commercially produced by a US glass company. This company has expressed interest in working with Plasmelt to more fully assess the benefits of plasma melting technology for their operations.
21. Approximately 400 # of good quality glass nuggets have been produced from a two-day period when the melting operation was very stable. These nuggets have been shipped to AGY for further fiberizing trials, which will be completed in April.

BUDGET / FINANCIAL

Overall, the project is on budget. We expect to spend the total DOE and cost share obligated monies by the end of the project, which is now scheduled for 7/27/05. However, since we have not yet met all of the original project objectives, we plan to file for a project extension to request additional funding and additional time beyond our scheduled end date.

Budget Data (as of 3/31/05): The actual spending should reflect the money actually spent on the project in the corresponding periods.

Project Spending and Estimate of Future Spending							
Quarter	**From**	**To**	**Estimated Federal Share of Outlays***	**Actual Federal Share of Outlays**	**Estimated Recipient Share of Outlays***	**Actual Recipient Share of Outlays**	**Cumulative**
	Start	9/30/04	Note 1	$856,828	Note 1	$365,391	$1,222,219
4Q04	10/1/04	12/31/04	Note 1	$147,664	Note 1	$ 44,904	$ 1,414,787
1Q05	1/1/05	3/31/05	Note 1	$86,008	Note 1	$ 27,119	$ 1,527,914
2Q05	4/1/05	6/30/05	$ 90,000		$40,500		$ 1,663,414
3Q05	7/1/05	9/30/05	$ 31,857		$42,086		$ 1,732,356
4Q05	10/1/05	12/31/05		Note 4		Note 6	
1Q06	1/1/06	3/31/06					
2Q06	4/1/06	6/30/06					
3Q06	7/1/06	9/30/06					
4Q06	10/1/06	12/31/06					
1Q07	1/1/07	3/31/07					
2Q07	4/1/07	6/30/07					
3Q07	7/1/07	9/30/07					
4Q07	10/1/07	12/31/07					
Totals			**$ 121,857**	**$1,090,500**	**$ 82,586**	**$437,414**	**$1,732,356**

* Update quarterly

General Note: DOE Laboratory partner spending should not be included in the above table. If a DOE Laboratory is a partner, report their spending and spend plan information in the table below (use separate tables if multiple DOE Laboratories are involved):
Note 1: Leave blank. Only the actual DOE/Cost Share amounts spent through 3/31/05 are needed.
Note 2: Amount for this quarter and subsequent quarters should be updated as necessary on a quarterly basis. Estimates need to be provided for the entire project. If spending for a given quarter is different than estimated, then the remaining quarter's estimates should be updated to account for the difference. Total DOE and Cost Share amounts should be the same as the Award amount.
Note 3: This should match the amount on the SF269A section 10.c. Column III (10.j. Column III on the SF269).
Note 4: This should match the amount on the SF269A section 10.c. Column II (10.j. Column II on the SF269).
Note 5: This should match the amount on the SF269A section 10.b. Column III (10.i. Column III on the SF269).
Note 6: This should match the amount on the SF269A section 10.b. Column II (10.i. Column II on the SF269).
Note 7: This should match the amount on the SF269A section 10.a. Column III (10.d. Column III on the SF269).
Note 8: This should match the amount on the SF269A section 10.a. Column II (10.d. Column II on the SF269).

Plans for Next Quarter:

- Complete the high throughput S-glass and E-glass trials to determine energy efficiency and glass quality
- Perform detailed glass quality assessments at Integrex and Monarch Analytical Laboratories
- Complete the 2-D math modeling work by LGP and use it to optimize design and operation of the plasma melter
- Produce large quantities (e.g. 1500 #) of good quality glass patties to be used for fiberization trials at AGY
- Conduct extensive fiberization and glass quality trials at AGY's Huntingdon facility with the plasma melted glass patties
- Continue the process experiments to attempt to further optimize energy efficiency
- Continue to refine torch designs as necessary to meet the 500 #/hr target throughputs and 100 hour life goals
- Complete the plasma physics work by Dr. Scott Parker of Colorado University

Patents: N/A

Publications/Presentations: N/A

Milestone Status Table: This should be a complete list of project milestones, anticipated completion dates and actual completion dates. The milestone identification number should correspond to the task numbers in your agreement to aid in tracking (example below).

ID Number	Task / Milestone Description	Planned Completion	Actual Completion	Comments
M 1	Project Startup: Establish WBS and Schedule, operating agreements, IP Terms, subcontract agreements	10/31/03	10/31/03	Complete
M 2.1	Melter Design: Develop Project Request Documents, specifications, materials lists, engineering packages	10/31/03	10/31/03	Complete
M.2.2	Laboratory Preparation: Identify candidate facilities, sign lease agreements, establish environmental permits	12/31/03	10/31/03	Complete. Notification of environmental Exemption Letter received from Colorado DPHE
M.2.3	Construct Melter: Subcontract fabrication and construction, install melter at site	12/31/03	2/29/04	Most of the delay due to major change in the building electrical system upgrade by Xcel Energy. Melter construction and fabrication are now complete.
M 3	Market Survey	5/31/04	5/31/04	Work is complete.
M 4	Melter/Process Test Program: Startup and operation at 500 #/hr rate [GO/NO GO DECISION], preliminary energy balance, preliminary report	7/27/04	In progress	Although 500#/hr has not yet been achieved on a routine basis, this work is ongoing. Long stable runs have been achieved at 300 #/hr but not at 500 #/hr. A report was issued to our team-members documenting our "GO" decision.
M 5	Assess Glass Quality: Patty Making Installation, Patty Production, and Fiberizing Testing [GO/NO GO DECISION]	1/31/05	In progress	Hand-made nuggets have been produced and are in transit to AGY. Initial fiberizing testing will begin in late April.
M 6.1	Optimization: Process refinement, energy balance updates [GO/NO GO DECISION]	6/30/05		
M 6.2	Final Reporting to DOE	Within 30 days of 7/27/05		

Measurement and Control of Glass Feedstocks

Weisberg: Energy Research Company, ORNL

ID14030, CPS#01609

QUARTERLY PROGRESS REPORT

Project Title: Measurement and Control of Glass Feedstocks

Covering Period: January 1, 2005 through March 31, 2005

Date of Report: May 6, 2005

Recipient: Energy Research Company
2571-A Arthur Kill Rd.
Staten Island, NY 10309

Award Number: DE-FC36-01ID14030

Subcontractors: Oak Ridge National Laboratory

Other Partners: PPG Industries
Fenton Art Glass

Contact(s): Arel Weisberg, Ph.D.
(718) 608-0935
aweisberg@er-co.com

Project Team: DOE-HQ Contact: Elliot Levine
Contract Specialists: Brad Ring, Beth Dwyer

Project Objective: Energy Research Company (ERCo) is developing an on-line sensor for controlling the quality of glass feedstocks, both batch and cullet. In the case of batch, the sensor can determine whether or not the batch was formulated accurately, and serve as part of a feedback loop in the plant to control glass quality. In the case of cullet feedstocks, the sensor can serve as part of a system to sort cullet by color and ensure that it is free of contaminants.

Background: The Glass Industry Technology Roadmap[1] emphasizes the need for accurate process and feedstock sensors. Listed first under technological barriers to increased production efficiency is the "Inability to accurately measure and control the production process." ERCo's LIBS sensor addresses this need by giving plant operators critical knowledge of their batch composition. In plants where cullet is used in glass production, the LIBS sensor can provide color sorted cullet free of contaminants,

[1] Available at: http://www.oit.doe.gov/glass/pdfs/glass2002roadmap.pdf

including those contaminants that are not detectable using current optical based color sorters.

LIBS utilizes a highly concentrated laser pulse to rapidly vaporize and ionize a small amount of the material being studied. As the resulting plasma cools it radiates light at specific wavelengths corresponding to the elemental constituents (e.g. silicon, aluminum, iron) of the material. The strengths of the emissions correlate to the concentrations of each of the elemental constituents. This technology has been successfully demonstrated in ERCo's LIBS laboratory for both batch analysis and cullet sorting. In the upcoming year, designs of prototype sensors for installation at the program's industrial partners will be developed.

Status:

1. **Executive Summary**

Activities this quarter included visits to PPG's research center in Pittsburgh, PA and a visit to PPG's Chester plant for scheduled maintenance on the LIBS batch analyzer. ERCo also took delivery of a key component for upgrading the Chester analyzer for analysis of the plant's scrubber limestone.

Progress during this quarter was limited for a review of the project's benefits to the glass industry by the program's mangers at DOE headquarters and the managing field office.

2. **Visit to PPG's Research Center**

Mr. Robert De Saro and Dr. Arel Weisberg of Energy Research Company visited with engineers at PPG's research center in Pittsburgh to review the LIBS batch analyzer project as well as discuss future business opportunities. PPG reviewed all the results to date in the project and expressed satisfaction with the project. They are looking forward the addition of the remaining capabilities to the analyzer so that its utility will be maximized.

Future business opportunities were also discussed, including collaboration on a proposal to DOE for LIBS measurements of molten glass in-situ in glass furnaces. These discussions included applications to both fiber glass and flat glass plants.

3. **Scheduled Maintenance Visit to PPG in Chester S.C.**

Dr. Jospeh Craparo of ERCo traveled to the Chester plant to service the LIBS batch analyzer. The laser requires quarterly maintenance consisting of a coolant flush. Dr. Craparo performed this service and checked for proper operation of all the components.

Plans for Next Quarter:

Pending a positive project review by DOE, ERCo will install the planned upgrade of the sample chamber described in prior reports during the next reporting period.

Patents: N/A

Publications/Presentations:

N/A

Milestone Status Table:

ID Number	Task / Milestone Description	Planned Completion	Actual Completion	Comments
1	Laboratory Development			
1.1	Facility Modification	9/30/01	9/30/01	
1.2	Testing	3/31/02	2/28/02	
1.3	Initial Software Development	3/31/02	3/31/02	
1.4	Performance Evaluation	3/31/02	3/31/02	
2	Sensor Fabrication			
2.1	Facility Construction	9/30/02	8/31/02	
2.2	LIBS Testing	8/31/03		Ongoing to add capabilities
2.3	Modifications to PPG Facility	12/31/03	3/31/04	
2.4	Procure System	6/30/04		Ongoing to add capabilities
3	Sensor Testing			
3.1	Testing at PPG	2/28/05		Commenced in 6/04
3.2	System Integration	12/31/04	8/24/04	

Budget Data (as of date):

Project Spending and Estimate of Future Spending							
Quarter	**From**	**To**	**Estimated Federal Share of Outlays***	**Actual Federal Share of Outlays**	**Estimated Recipient Share of Outlays***	**Actual Recipient Share of Outlays**	**Cumulative**
	Start	6/30/04	Note 1	904,873.18	Note 1	784,137.42	1,689,010.60
3Q04	7/1/04	9/30/04	Note 2	1,109,175.19	Note 2	784,137.42	1,893,312.61
4Q04	10/1/04	12/31/04	1,127,725.19	1,109,175.19	984,137.42	784,137.42	2,789,183.19
1Q05	1/1/05	3/31/05	1,438,813.00	1,129,178.00	1,680,008.00	1,605,006.00	2,734,184.00
2Q05	4/1/05	6/30/05					
3Q05	7/1/05	9/30/05					
4Q05	10/1/05	12/31/05					
Totals			**2,566,538.19**	**Note 3**	2,664,145.42	**Note 5**	**Note 7**

* Update quarterly

General Note: DOE Laboratory partner spending should not be included in the above table. If a DOE Laboratory is a partner, report their spending and spend plan information in the table below (use separate tables if multiple DOE Laboratories are involved):
Note 1: Leave blank. Only the actual DOE/Cost Share amounts spent through 6/30/04 are needed.
Note 2: Amount for this quarter and subsequent quarters should be updated as necessary on a quarterly basis. Estimates need to be provided for the entire project. If spending for a given quarter is different than estimated, then the remaining quarter's estimates should be updated to account for the difference. Total DOE and Cost Share amounts should be the same as the Award amount.
Note 3: This should match the amount on the SF269A section 10.c. Column III (10.j. Column III on the SF269).
Note 4: This should match the amount on the SF269A section 10.c. Column II (10.j. Column II on the SF269).
Note 5: This should match the amount on the SF269A section 10.b. Column III (10.i. Column III on the SF269).
Note 6: This should match the amount on the SF269A section 10.b. Column II (10.i. Column II on the SF269).
Note 7: This should match the amount on the SF269A section 10.a. Column III (10.d. Column III on the SF269).
Note 8: This should match the amount on the SF269A section 10.a. Column II (10.d. Column II on the SF269).

DOE Laboratory Spending Table (if applicable):

DOE Laboratory Partner Spending and Estimate of Future Spending					
Quarter	**From**	**To**	**Estimated DOE Lab Amount***	**Actual DOE Lab Amount**	**Total**
	Start	6/30/04	Note 1	155,000.00	155,000.00
3Q04	7/1/04	9/30/04	Note 2	0	0
4Q04	10/1/04	12/31/04			
1Q05	1/1/05	3/31/05			
2Q05	4/1/05	6/30/05			
3Q05	7/31/05	9/30/05			
4Q05	10/1/05	12/31/05			
1Q06	1/1/06	3/31/06			
Etc.					
Totals				**155,000.00**	**155,000.00**

* Update quarterly

Developing the Glass Industry Vision and Roadmap

Greenman: Glass Manufacturing Industry Council

ID14315, CPS#01034

As of June 1, 2005, the PI has not submitted an updated status report for the period ending March 31, 2005. The following is the most recent status report submitted:

DOE F 4600.6
(10-94)
Replaces EIA-459F
All Other Editions
Are Obsolete

U.S. Department of Energy

OMB Control No.
1910-0400

FEDERAL ASSISTANCE PROGRAM/PROJECT STATUS REPORT

OMB Burden Disclosure Statement

Public reporting burden for this collection of information is estimated to average 47.5 hours per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Office of Information Resources Management Policy, Plans, and Oversights, Records Management Division, HR-422 - GTN, Paperwork Reduction Project (1910-0400), U.S. Department of Energy, 1000 Independence Avenue, S.W., Washington, DC 20585; and to the Office of Management and Budget (OMB), Paperwork Reduction Project (1910-0400), Washington, DC 20503.

1. Program/Project Identification No.	2. Program/Project Title	3. Reporting Period
DE-FC36-02ID14315	Promotion of the U.S. Glass Industry	10/1/04 to 12/31/04

4. Name and Address	5. Program/Project Start Date
Michael Greenman Glass Manufacturing Industry Council PO Box 6136 Westerville, OH 43081	4/01/02
	6. Completion Date 3/31/05

7. Approach Changes

No changes since last reporting period.

8. Performance Variances, Accomplishments, or Problems

The Technical and Economic Assessment: The document was completed, printed, and distributed. Initial reports have been very complimentary regarding the content and value of the document. The book can be ordered from the GMIC and a PDF file is available on our web site for download at no cost.

The GMIC will arrange and host meetings for the glass industry: In conjunction with the Glass Problems Conference, we organized a ½ day workshop entitled: "Innovation in glass – Growing the Glass Market". Purpose was to identify needs for future research areas to improve glass industry efficiency and competitiveness.
--At American Ceramic Society's – Glass and Optical Materials Division, the GMIC organized two information sessions: – "Melting technologies", and "Adding Value to Glass". 15 presentations described the status of current research and in-place technologies currently making or with the potential to contribute improvements in glass melting and forming efficiencies.
--We organized a two-conference to discuss opportunities for improving available technologies in glass by developing collaboration between leading glass artists and glass technologists whose various approaches to "working" with glass may well yield innovative technologies of benefit to industry and art.

Ongoing monitoring and evaluation of research projects: A board-level "Project Management Committee" was created to perform regular oversight visits to active research projects. A plan was established to meet with all Principal Investigators on a scheduled basis.

The GMIC will identify any existing or planned collaborative opportunities between industry, National Laboratories, Universities, etc. which relate to the Glass Industry Vision and Roadmap: The Council is developing coalitions to be prepared to respond to the upcoming Glass research solicitation in the areas of refining technologies to be matched to currently developing "Next Generation Melting" technologies.

9. Open Items

GMIC is beginning a discussion with the DOE to plan for the 2005 Project Review and to initiate a process to update the Technology Roadmap.

10. Status Assessment and Forecast

Nine new members have joined the GMIC since the beginning of the year: four glass companies, one national lab and four suppliers. Industry acceptance of the value of the GMIC is growing and permitting the development of programs in new areas with broader focus. It is expected that this growth will continue in 2005 leading to a situation in which the vast majority of the industry is collaborating for mutual improvement.

11. Description of Attachments

12. Signature of Recipient and Date	13. Signature of U.S. Department of Energy (DOE) Reviewing Representative and Date
Michael Greenman – 1/31/05 (by e-mail)	

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Index of HQ CPS and Award CID Numbers

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